Research Report
472

EFFECTIVENESS OF GREEN-EXTENSION SYSTEMS AT HIGH-SPEED INTERSECTIONS

KYP-75-69, HPR-PL-1(12); Part III B

by

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Waiting for a green light at a signalized intersection when no other vehicle is in sight is a seemingly needless servitude to the rules of the road. To be beckoned onward by a green light and a clear road -- only to be outwitted by a guileful timer -- and then be required to stop is an outrage. Of course, these same thoughts inspired the development of treadle-type magnetic-type switches and loop-type presence detectors which are built into the approach pavement. Perhaps the desire far preceded the technology and economic feasibility. Maybe we are still far short of ideal, intersection control. Nevertheless, the green-light-extension system evaluated in the report submitted herewith has an amazing, potential payoff when used as intended.

Respectfully submitted,

Jas. H. Havens

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Director of Research

gd
Enclosure
cc's: Research Committee

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16. Abstract

The purpose of this study was to determine the effectiveness of green-extension systems (GES) for reducing the dilemma-zone problem associated with the amber phase of traffic signals at high-speed intersections. Reactions of 2,100 drivers were noted during the amber phase at nine intersections, and the dilemma-zone distances with respect to the stop bar were determined.

Before-and-after studies made at three green-extension sites showed a 54-percent reduction in total accidents and a 75-percent reduction in rear-end accidents after GES installation. Accident severity was unaffected.

Conflict, volume, delay, and speed data were taken before and after GES installation at two sites. A 62-percent reduction in yellow-phase conflicts was noted after green extension was provided, and conflict rates decreased significantly at both sites. No significant change was found in vehicle delay due to green extension.

Expected present-worth benefits due to GES installations were found to range from $29,000 to $420,000, depending on the history of rear-end accidents. Benefit-cost ratios ranged from 6 to 70.

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INTRODUCTION

When approaching a traffic signal during the green phase in the general range of 35 to 55 mph (15.6 to 24.6 m/s). a driver confronts the alternative of proceeding through the intersection or anticipating a change to amber and attempting to stop. This is sometimes referred to as the "dilemma zone" with reference to the decision-making required by the driver. Inappropriate or bad decisions by some drivers result in numerous rear-end and right-angle collisions at intersections where the flow of traffic is at a fairly high speed.

Intersections in rural areas often have accident buildups where a sight distance problem exists and where high speeds of approaching vehicles results in insufficient time for perception, reaction, and braking. In similar situations, there have been attempts to decrease the number of rear-end and right-angle collisions by installing green-phase extension systems (GES systems) *(1)*. These systems include presence-detection loops in the pavement preceding the intersection which transmit messages to a receiver in the signal control box. Thus, an extension of the green phase is possible. This occurs only if a vehicle is passing over the detector within an interval which has been predetermined as the dilemma zone. An extension of the green phase at this point permits the vehicle to proceed onward through the intersection without having to stop abruptly to avoid running a red light.

Kentucky has several installations of GES systems. There are presently 16 intersections with various modifications of GES systems, and plans have been made for several more. While these systems should theoretically increase safety and reduce rear-end and right-angle accidents, very little data are available to verify their effectiveness. Also, since the green phase is extended on the major approaches only, delay would be expected to increase on the side streets. The extent of such added delay has not been determined for various traffic volumes.

One uncertainty regarding installation of GES systems involves determining the distances from the stop bar which best approximates the dilemma zone in Kentucky. Several previous studies give different limits for various vehicle speeds. The effect of the GES systems on traffic speeds, intersection delay, traffic accidents, and vehicle conflicts needed to be determined for urban and rural conditions and under different geometric and volume conditions. The effectiveness of different modifications of GES systems needed testing to determine optimal applications to various types of intersections. General guidelines and warrants also needed to be developed for use by traffic engineers when selecting sites for installation of GES systems.

DILEMMA ZONE

To determine the length of the dilemma zone, driver responses were recorded at nine high-speed intersections in Lexington and Louisville (see Table 1). All intersections were on four-lane, divided arterials. At each approach, distances were measured from the stop bar to the end points of each dashed-type lane stripe back to about 600 feet (183 m). Reference diagrams were drawn showing the number of lane stripe from the stop bar with each corresponding distance. A state car was parked on the right shoulder about 200 feet (61 m) back from the intersection.

Two observers were used to record the data: one monitored the speed of each vehicle approaching the intersection, and the other watched for the yellow indication. The instant that the yellow was displayed, the location of any vehicle within 600 feet (183 m) of the intersection was observed in terms of a specific paint stripe. The distance from the stop bar to the vehicle was found quickly from the reference diagram within an accuracy of about 5 feet (1.5 m). The vehicle speed was also recorded along with the vehicle type and whether it stopped or proceeded through the intersection. During many yellow phases, no vehicles were within the 600 feet (183 m) interval; responses of two vehicles were recorded during a few yellow phases. Responses of about 2,100 drivers to the yellow phase were recorded in this manner.

Motorists included in the data collection were travelling straight with no left- or right-turning vehicles included. No data were recorded under congested conditions or when the speed of a vehicle was influenced by any other vehicle. For example, if two cars were in the same lane when the yellow light appeared, the car following was not recorded if the first car stopped, since the second car had to stop to avoid a collision. All classifications of vehicles were recorded, and trucks (six tires and larger) were analyzed separately from cars. No significant differences in driver reactions were noted between cars and trucks. However, only straight, level intersection approaches were used. The response of truck drivers on downgrade approaches should be tested.

To analyze the data, responses were first classified by speed. For example, vehicles from 38 to 42 mph (17 to 19 m/s) were classified as 40 mph (18 m/s), vehicles from 43 to 47 mph (19 to 21 m/s) were classified as 45 mph (20 m/s) and so on. The next data summary was by "stopping" and "non-stopping" vehicles. Ranges of distances of 10 feet (3 m) were used for tabulating the number of drivers in each group. If 22 percent of all 50-mph (22-m/s) drivers stopped at a distance of 200 feet (61 m), then that point was plotted for the 50-mph (22-m/s) curve. A set of curves for speeds of 35 to 55 mph (16 to 25 m/s) was drawn from the data as shown in Figure 1.

TABLE 1. SITES OF DATA COLLECTION FOR DILEMMA-ZONE ANALYSIS

LOUISVILLE
Bardstown Road at Breckinridge Lane
Newberg Road at Bashford Manor
Taylorsville Road at Six Mile Road
LEXINGTON
Nicholasville Road at Wilson Downing Road
New Circle Road at Woodhill Drive
New Circle Road at Richmond Road
Versailles Road at Parkers Mill Road
North Broadway at ramp to I 64 and I 75
Tates Creek Pike at Gainesway Drive

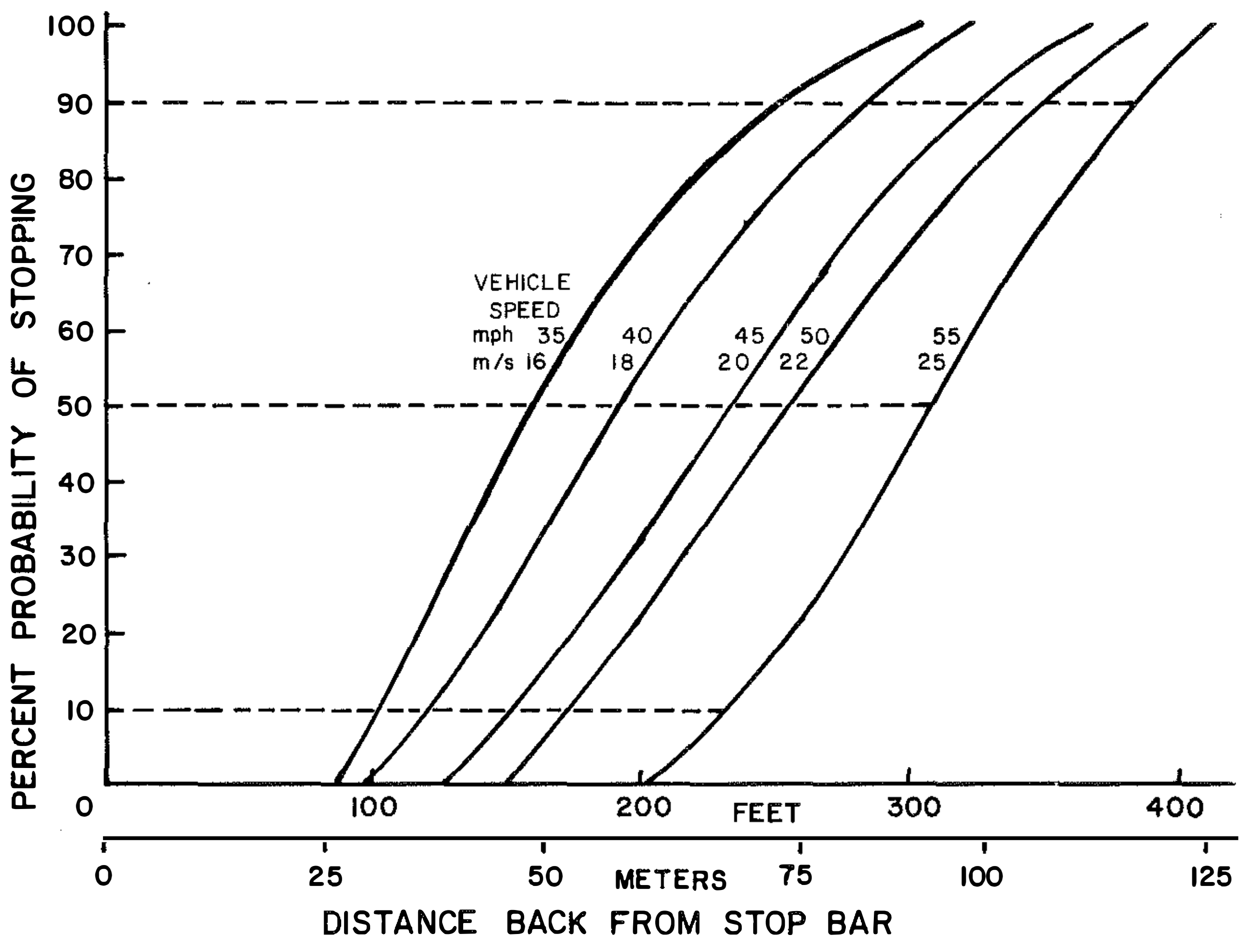


Figure 1. Dilemma-Zone Curves for Kentucky Drivers.

The probability of stopping is shown for five different speeds as related to the distance of the vehicle from the intersection in Figure 1. At 55 mph (25 m/s), about 20 percent of all motorists will stop if the yellow appears when they are 255 feet (78 m) from the intersection. The dilemma zone has been arbitrarily defined to be a probability of stopping of between 10 and 90 percent *(1)*. Distances corresponding to these probability levels are given in Table 2 along with distances for 50-percent probability of stopping. These distances were taken from Figure 1 and indicate the dilemma zone from the Kentucky data. For example, the dilemma zone for motorists travelling 45 mph (20 m/s) is from 152 to 325 feet (46 to 99 m).

The dilemma-zone distances from the Kentucky data were compared with data from Olson and Rothery *(2)*, Webster and Ellson *(3)*, Parsonson, et al. *(1)*, Crawford and Taylor *(4)*, Herman *(5)*, and the Minnesota Department of Highways *(6)* in Tables 3 and 4. The distances of the Kentucky data are very close to most of the references for a 10-percent stopping probability. At 50 mph (22 m/s), the 170-foot (52-m) distance is lower than the other values. At the 90-percent probability level, the distances for Kentucky data are slightly higher than the others at 35 to 45 mph (16 to 20 m/s). The high-speed distances are in close agreement with the other studies. Because of the differences in collection techniques and dilemma zone distances by the various other studies, this dilemma zone analysis was intended for application in Kentucky in placement of loops for green extension systems. The spacing of both loops of a two-loop GES system can be easily found for any vehicle speed from Figure 2. This figure was constructed using the distances corresponding to different speeds with probabilities of stopping of 10 and 90 percent from Figure 1.

The grade of an approach leg can significantly affect the stopping distances of vehicles. Grades should, therefore, be taken into account when determining loop distances for green extension systems. The formula for minimum safe stopping distances *(7)* was used to determine adjustments to be used when computing loop distances:

$$D = 1.47\ Vt + V^2/30\,(f \pm G)$$

where D = minimum safe stopping distances,
V = vehicle speed in mph,
t = driver reaction time (2.5 seconds),
f = coefficient of friction (skidding when wet), and
G = grade, in percent.

The driver reaction time was taken to be 2.5 seconds. The coefficient of friction was assumed to be 0.3 and pertains to wet-road conditions at speeds around 60 mph (27 m/s). Comparing the minimum safe stopping distances (D) for vehicle speeds of 35 to 55 mph (16 to 25 m/s) with grades between -8 and +8 percent, a set of curves for adjusting loop distances was constructed as shown in Figure 3. The value of D for each grade was compared with the D of zero grade, and the difference was plotted for various speeds. At a speed of 45 mph (20 m/s) on a 6-percent downgrade, an adjustment of 55 feet (17 m) should be added to loop distances as computed from the dilemma zone curves. On an upgrade of 8 percent at 55 mph (25 m/s), an adjustment of -70 feet (21 m) should be made. These values are slightly higher (using 0.30 for f) than adjustments given by AASHTO *(8)*.

TABLE 2. LOOP SPACINGS FOR KENTUCKY INTERSECTIONS

VEHICLE SPEED		10 PERCENT OF STOPS		50 PERCENT OF STOPS		90 PERCENT OF STOPS	
mph	m/s	ft	m	ft	m	ft	m
35	16	103	31	162	49	254	77
40	18	121	37	210	64	283	86
45	20	152	46	233	71	325	99
50	22	170	52	255	78	350	107
55	24	232	71	308	94	384	117

TABLE 3. DETECTOR SET-BACKS FOR DILEMMA ZONE WITH A 10-PERCENT PROBABILITY OF STOPPING

APPROACH SPEED		DISTANCE FROM INTERSECTION IN FEET (m)				
mph	m/s	OLSON AND ROTHERY *(2)*	WEBSTER AND ELLSON *(3)*	PARSONSON *(1)*	HERMAN *(5)*	KENTUCKY
30	13	95 (29)	80 (24)	100 (30)	90 (27)	
35	16	103* (31)	103* (31)	105* (32)	100* (30)	103 (31)
40	18	110 (34)	125 (38)	110 (34)	110 (34)	121 (37)
45	20	165* (50)	155* (47)	165 (50)	165* (50)	152 (46)
50	22	220 (67)	185 (56)	220 (67)	220 (67)	170 (52)
55	25		230* (70)	240* (73)		232 (71)
60	27		275 (84)	260 (79)		
65	29		338 (103)			
70	31		400 (122)			

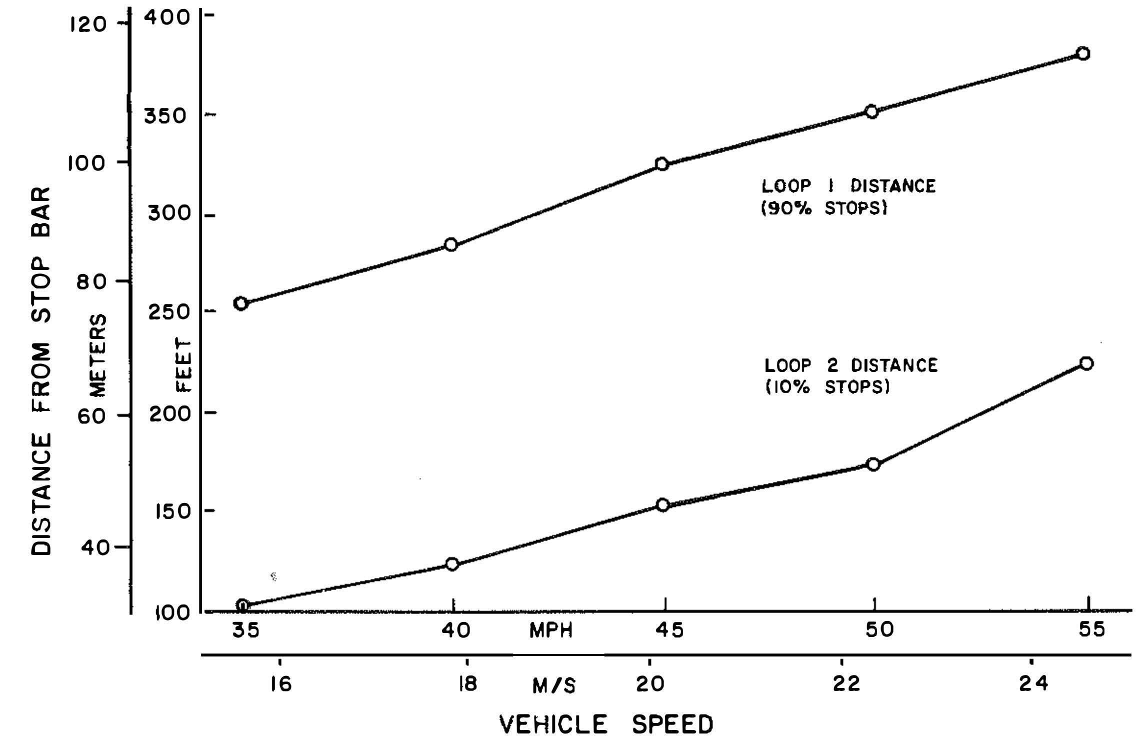
Note: Minnesota data not available for 10-percent probability
*Interpolated values

TABLE 4. DETECTOR SET-BACKS FOR DILEMMA ZONE WITH A 90-PERCENT PROBABILITY OF STOPPING

APPROACH SPEED		DISTANCE FROM INTERSECTION IN FEET (m)					
mph	m/s	OLSON AND ROTHERY *(2)*	WEBSTER AND ELLSON *(3)*	PARSONSON *(1)*	HERMAN *(5)*	MINNESOTA *(6)*	KENTUCKY
30	13	170 (52)	135 (41)	175 (53)	175 (53)	140 (43)	
35	16	212* (65)	170* (52)	212* (65)	218* (66)	178* (54)	254 (77)
40	18	255 (78)	205 (62)	250 (76)	260 (79)	215 (66)	283 (86)
45	20	315* (96)	252* (77)	300 (91)	315* (96)	258* (79)	325 (99)
50	22	375 (114)	300 (91)	350 (107)	370 (113)	300 (91)	350 (107)
55	25		370* (113)	400* (122)		375* (114)	384 (117)
60	27		440 (134)	450 (137)		450 (137)	
65	29		525* (160)				
70	31		650 (198)				

*Interpolated values

Figure 2. Proposed Vehicle-Loop Spacings for GES Systems.



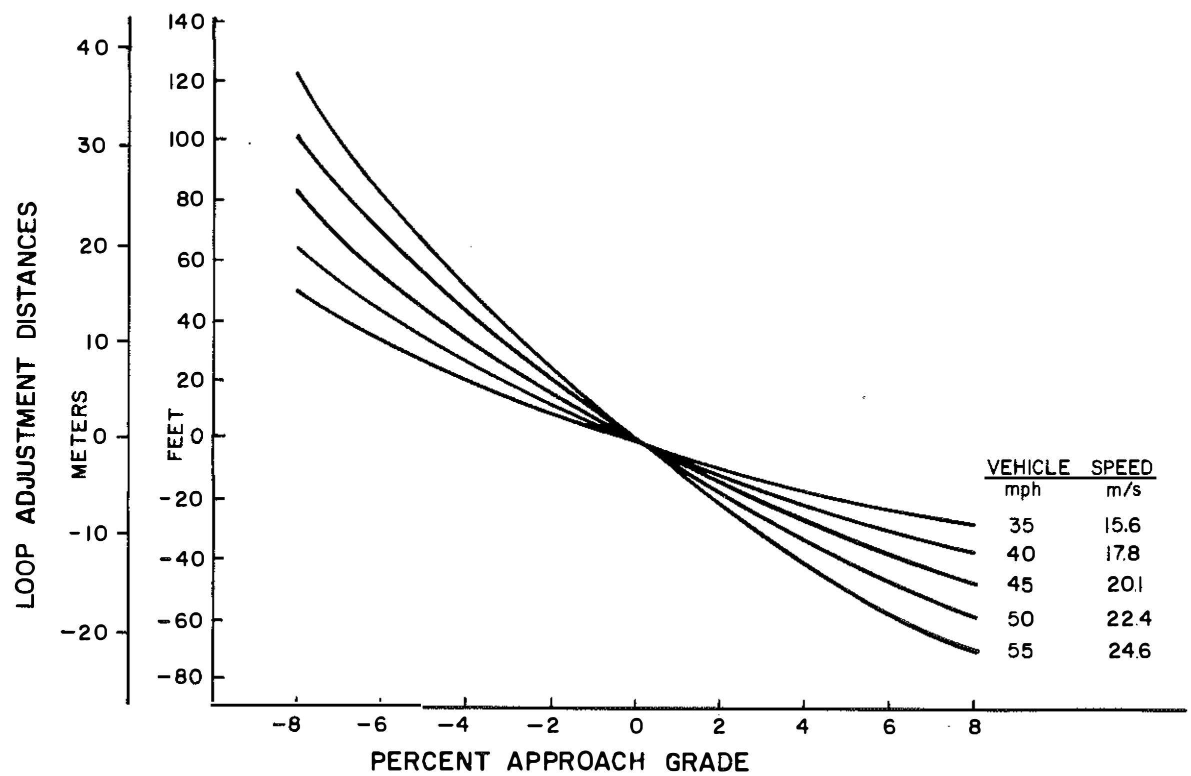


Figure 3. Adjustments for Loop Spacings for Approach Grades.

USE OF GREEN-EXTENSION SYSTEMS

Green-extension systems (GES) extend the green phase of a traffic signal to allow a vehicle or a platoon of vehicles to clear the intersection before the yellow indication is given. They may be used with semi-actuated, basic full-actuated, or pretimed controllers, although they are usually used with traffic-actuated signals. Green extension is normally installed on both intersection approaches of a major arterial street. However, they may be installed on only one approach in case of a steep downgrade or on all four approaches where two high-speed arterials intersect *(1, 9)*.

To use green extension, either two or three multilane, vehicle-detection loops are normally placed in advance of the signal on each approach. Although more than three loops could be used, two are the most common. Three loops are sometimes needed on approaches with steep downgrades, where high truck volumes exist, or where average traffic speeds exceed 45 mph (20 m/s). Loop distances upstream from the stop bar should be based on the dilemma zone of the approach, as discussed earlier. The loop spacings usually correspond to travel times of about 2 to 5 seconds in advance of the stop bar. Based on Kentucky dilemma zone curves (Figure 2), loop spacings for a two-loop system would be about 152 and 325 feet (46 and 99 m) in advance of the stop bar for speeds of 45 mph (20 m/s). The 85th-percentile speed is normally used for determining loop spacings.

Loop 1 in a green extension setup refers to the first loop encountered by a vehicle approaching the intersection. In most cases, Loop 1 on one approach is connected in parallel to the same detector as Loop 1 on the opposite approach. The second loops are connected in a similar manner. Such loops are made to cover all traffic lanes and are generally 4 feet long. The passage of a vehicle over Loop 1 activates the extension timer which stretches the green time for a pre-determined number of seconds. Another extension of green time is made after passage over Loop 2 to assure clearance of the vehicle through the intersection. More details of the operation of green extension systems are available from several sources *(1, 9, 10)*.

The Division of Traffic in Kentucky has experimented with various modifications of green extension. Guidelines were recently prepared for green extension system operation. The guide includes general warrants and a discussion of vehicle detection, controller settings, and other considerations. A copy of "Green Extension System Operation and Installation" is presented in APPENDIX A.

Installation of GES is considered when accidents (particularly rear-end type) occur at a high rate or when a stopping or dilemma-zone problem is found. Green extension is considered with the installation of a new signal when the intersection has a sight distance deficiency, excessive grade on one or more approaches, or where approach speeds exceed 40 mph (18 m/s). In-depth traffic studies are made at all locations which are considered for green extensions. Such studies may include approach speed (by vehicle type), volume counts, headways and gaps, and effects of physical characteristics such as grades, surface type, drainage, and turning lanes.

The use of GES with an existing signal system is applied in three different manners in Kentucky. The ideal situation is in a rural area where traffic volumes are not high enough during any period of the day to cause congestion. Traffic speeds remain high and adequate gaps exist on the major street so that sufficient green intervals are given to side-street vehicles. In this case, the green extension is not preset to shut off for an excessive side-street delay. The intersection of US 27 and US 150 in Stanford is an example of this setup. A second case is where traffic is generally free flowing except for certain times when traffic may temporarily become congested. In this case, a preset maximum time is used to cut off the extended green after a specified period (usually 99 seconds) and gives the green phase to the side street. The intersection at US 23 and Hoods Creek Pike in Ashland was timed in this manner. The third method involves traffic which is congested daily during morning and afternoon peak hours. In this case, the green light extension is automatically turned off during these times. The intersection of US 421 and Shenkel Lane in Frankfort is an example of this setup.

Two-loop systems are generally used with green extension, and loop spacing is based on the 85th-percentile speeds. However, for locations with steep grades or high truck volumes, other modifications are sometimes used. The intersection of US 25E and US 25 in Corbin, for example, had a number of serious accidents involving coal trucks which failed to stop on a steep downgrade approach. A three-loop configuration was installed where the first loop was located based on the 95th-percentile speed; the accident problem at this location was greatly reduced. The use of truck-detection loops is currently under consideration in Kentucky for application to such intersections. These loops would be used in addition to loops for cars.

The GES in Kentucky and their location, type of control, installation date, and loop spacings are listed in Table 5. The systems range from two-phase to eight-phase signals, and they are equally divided between full- and semi-actuated control. The first green extension system in Kentucky was installed on the US 60 Bypass at Big Sink Pike in Versailles on August 18, 1972. There are currently two locations with the three-loop configurations and others with two loops. A map showing the green extension locations in Kentucky is given in Figure 4.

Several other state and local highway agencies have been using green extension since 1972. The North Carolina Department of Transportation has about 50 installations in operation on state-maintained roads. Only two-loop installations have been used to date, but three-loop systems have been proposed. Also under consideration in North Carolina is the use of truck detectors to be used in conjunction with GES systems at a location having a steep downgrade and high truck volumes. Green extension systems are used at signals with up to eight phases and with cycles up to 180 seconds (North Carolina). To prevent extremely long waiting periods on side streets, the green extension is set to terminate after 90 seconds in most cases (cutoffs after 120 seconds are sometimes used) *(11)*.

New installations of signals in Huntsville, Alabama, on high-speed arterials are now supplemented with green extension on major approaches. About 24 GES's have been installed in Huntsville since 1972. All were two-loop installations. Floating-car studies were made through five, adjacent, signalized intersections before and after a change from a coordinated signal system to green extension. On the major approaches, the number of stops and travel time were reduced after installation of green extension systems. Although the use of green extension is usually associated with increased side-street delay, it may be possible in some cases to reduce that delay *(12)*.

One study showed a reduction in accidents at three intersections after installation of GES. All intersections were in Charlotte, North Carolina, and had speed limits of 35 mph (16 m/s). One year of before and one year of after data was used in the analysis. Although traffic volumes increased by 17 percent during the after period, there was a combined accident reduction of 68 percent at the three intersections. Two of the intersections were four-way and the other was a T-intersection. One of three intersections included a six-lane, divided arterial and the other two were divided, four-lane arterials *(13)*.

One of the problems found with GES is the maintenance of loops imbedded in the pavement. They sometimes de-tune, or stop operating, and may cause severe problems. Local agencies responsible for maintenance of the systems do not always repair them soon after failure. Many signal maintenance personnel do not completely understand the green extension units or how they should operate *(14)*. The problem of loop wires being accidentally cut by various utility companies and shoulder maintenance teams was also noted in North Carolina. Local agencies are reimbursed by the North Carolina Department of Transportation for maintaining traffic signals *(11)*.

ACCIDENT ANALYSIS

To determine the effect of green extension in reducing traffic accidents, before and after analyses were made at several sites. Sites used for these analyses must have had a green extension system installed at an existing signal location. After reviewing the 16 GES locations in Kentucky, it was found that seven systems were installed along with traffic signals. Before that, these locations had stop signs. There were four locations where green extension had been installed recently, and, therefore, after accident data was not yet available. At another location, other improvements, including addition of separate left-turn phasing were installed along with the GES; accident records there reflected several improvements. The GES at one location was found to be inoperative on several occasions. The accident data at that location, therefore, was considered unreliable. Due to the elimination of the before-cited locations, only three locations remained which could be used in an accident analysis.

The first location analyzed was US 41A (four-lane, divided highway) at Gate 6 in Ft. Campbell in Christian County (AADT = 15,408). It was a three-phase, fully-actuated signal at a T-intersection with GES loop spacings on US 41A at 500 and 150 feet (154 and 46 m). The second location was US 25E at KY 312 in Corbin in Laurel County (AADT = 7,043). It was an eight-phase, fully-actuated signal at a four-way intersection with GES loop spacings on US 25E of 600, 500, and 175 feet (183, 154, and 53 m). The third location was on US 25E at KY 225 in Barbourville, Knox County (AADT = 11,000). It was a two-phase, fully-actuated signal at a four-way intersection. Loop spacings were set at 575 and 200 feet (175 and 61m).

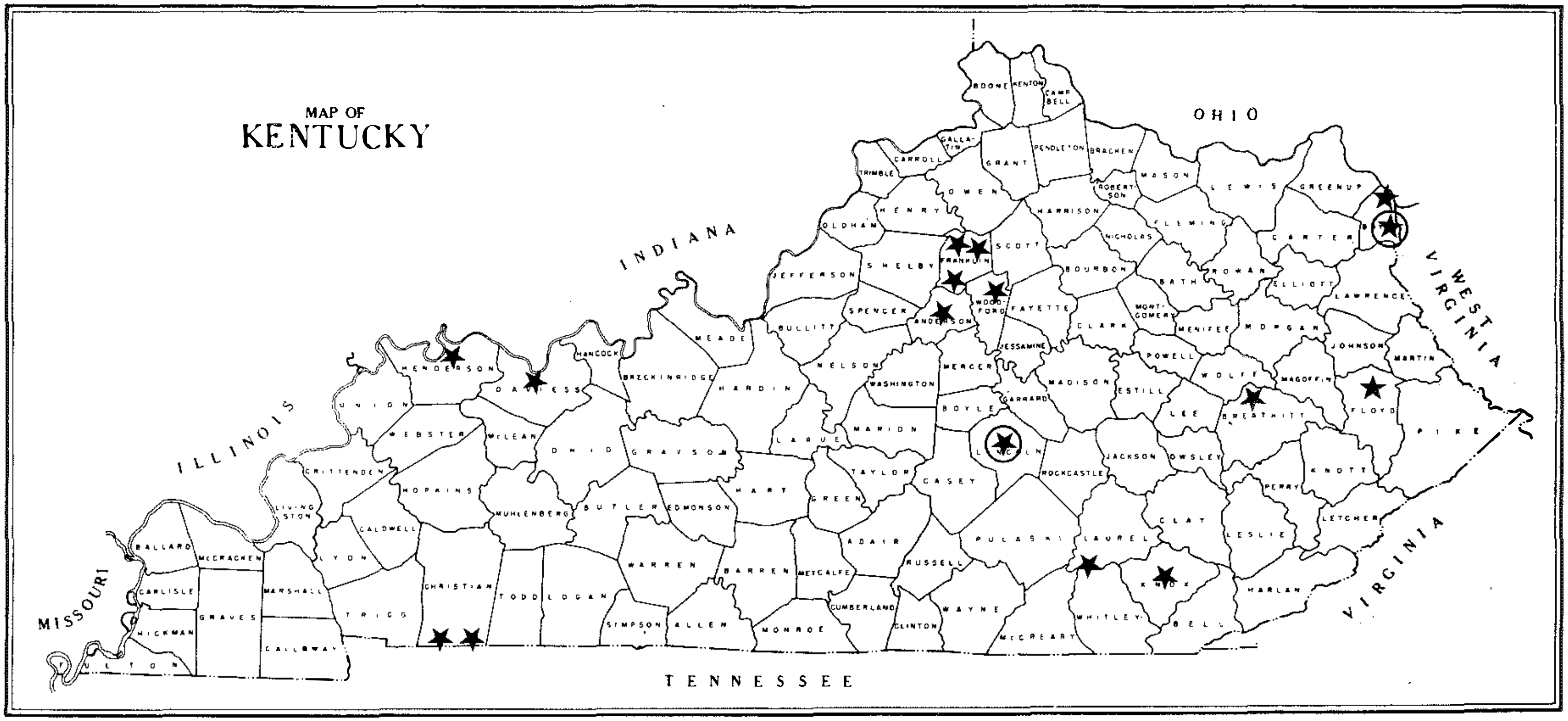
Because of the small number of locations, accident data were gathered for several years before GES installation and all available after data were used to increase the sample size. For the accident analysis, a combined total of 8.5 years of before data and 3.7 years of after data were used for the three locations. There were a total of 70 accidents before GES and 14 accidents after, or 8.2 and 3.8 accidents per year, respectively. This was a reduction of about 4.4 accidents per year, or 54 percent.

TABLE 5. INTERSECTIONS WITH GREEN-EXTENSION SYSTEMS

				PRESENT CONTROL		LOOP SPACINGS					
DISTRICT	COUNTY	CITY	INTERSECTION	TYPE	INSTALLATION DATE	LOOP 1		LOOP 2		LOOP 3	
						ft	m	ft	m	ft	m
2	Daviess	Owensboro	US 60 and KY 144	2φ*, Semi	10/12/72	450	137	300	91		
2	Henderson	Henderson	US 41 and Marywood Dr.	5φ, Semi	12/4/74	500	152	150	46		
2	Christian	Ft. Campbell	US 41A and Gate 6	3φ, Full	11/21/74	500	152	150	46		
5	Franklin	Frankfort	US 60 and Hanley Lane	2φ, Semi	5/9/73	450	137	150	46		
5	Franklin	Frankfort	US 127 and Collins Lane	2φ, Semi	2/14/75	650	198	200	61		
5	Franklin	Frankfort	US 421 and Shenkel Lane	3φ, Full	8/30/74	420	128	160	49		
7	Anderson	Lawrenceburg	US 62 and US 127	2φ, Semi	5/27/75	530	162	230	70		
7	Woodford	Versailles	US 62 and Big Sink Pike	2φ, Semi	8/18/72	400	122	150	46		
8	Lincoln	Stanford	US 27 and US 150	2φ, Semi	5/25/76	450	137	150	46		
9	Boyd	Ashland	US 23 and Hoods Creek Pk.	2φ, Semi	5/17/76	450	137	300	91	150	46
10	Breathitt	Jackson	KY 15 and KY 30	3φ, Full	10/10/75	450	137	175	53		
11	Laurel	Corbin	US 25E and KY 312	8φ, Full	8/10/73	500	152	175	53		
					4/14/76	600	183	500	152	175	53
11	Knox	Barbourville	US 25E and KY 225	2φ, Full	5/23/74	575	175	200	61		
12	Floyd	Allen	US 23 and KY 80	3φ, Full	12/12/73	600	183	200	61		
2	Christian	Ft. Campbell	US 41A and Gate 4	3φ, Full	11/17/76	370	113	165	50		
9	Boyd	Ashland	US 23 and Viney Br. Rd.	2φ, Full	12/9/76	450	137	175	53		

*Phase

Figure 4. Location of Green-Extension Systems in Kentucky.



★ GREEN EXTENSION LOCATIONS

(★) GREEN EXTENSION LOCATIONS WHERE BEFORE - AFTER DATA WERE TAKEN

The accidents were classified by type as shown in Table 6. Rear-end accidents were reduced about 75 percent (from 3.3 to 0.8 per year). Right-angle accidents decreased about 31 percent (from 3.9 to 2.7 per year), and other types of accidents experienced minor reductions. Summaries of property damage (PDO), injury, and fatal accidents are shown in Table 7. The number of each type of accident was reduced approximately by a half after installation of GES.

To determine the change in severity of an average accident, the severity index was calculated. The severity index formula was developed for Kentucky earlier *(15)*. Using the cost of each type of accident and injury and the number of accidents and injuries, weighting factors for the various injury types were obtained:

$$SI = (9.5(K + A) + 3.5(B + C) + PDO)/N$$

where SI = severity index,
K = number of fatal accidents,
A = number of A-type injury accidents,
B = number of B-type injury accidents,
C = number of C-type injury accidents,
PDO = number of property damage only accidents, and
N = the total number of accidents.

Using the severity index formula, the maximum SI value is 9.5 and would occur if all accidents were fatal or A-type injury accidents. The minimum SI value is 1.0 and occurs when all accidents are property damage only. Accidents by type of injury are given in Table 8, which was used to calculate the severity index. The severity index for the before period was 2.54; it was 2.57 after the GES installation. Therefore, there was no change in accident severity. This is not surpising since rear-end accidents are usually not too severe and inasmuch as these types of accidents experienced the greatest reduction. The percentages of PDO, injury, and fatal accidents were also found to be virtually unchanged (see Table 9).

TABLE 6. CLASSIFICATION OF ACCIDENTS BEFORE AND AFTER INSTALLATION OF GREEN-EXTENSION SYSTEM (THREE LOCATIONS)

	ACCIDENTS		ACCIDENTS PER YEAR	
TYPE OF ACCIDENT	BEFORE PERIOD (8.5 YEARS)	AFTER PERIOD (3.7 YEARS)	BEFORE PERIOD	AFTER PERIOD
Rear End	28	3	3.3	0.8
Right Angle	33	10	3.9	2.7
Sideswipe	4	0	0.5	0.0
Other	5	1	0.6	0.3
Total	70	14	8.2	3.8

TABLE 7. SEVERITY OF ACCIDENTS BEFORE AND AFTER INSTALLATION OF GREEN-EXTENSION SYSTEM (THREE LOCATIONS)

TYPE OF ACCIDENT	ACCIDENTS		ACCIDENTS PER YEAR	
	BEFORE PERIOD (8.5 YEARS)	AFTER PERIOD (3.7 YEARS)	BEFORE PERIOD	AFTER PERIOD
Property Damage	45	10	5.3	2.7
Injury	23 (44)*	4 (6)	2.7 (5.2)	1.1 (1.6)
Fatal	2 (3)	0 (0)	0.2 (0.4)	0 (0)
Total	70	14	8.2	3.8

*( ) Number of injuries

TABLE 8. ACCIDENTS BY TYPE OF INJURY BEFORE AND AFTER INSTALLATION OF GREEN-EXTENSION SYSTEM (THREE LOCATIONS)

TYPE OF ACCIDENT	BEFORE PERIOD	AFTER PERIOD
Property Damage Only	46	10
C-Type Injury	9	0
B-Type Injury	7	2
A-Type Injury	6	2
Fatal	2	0
Total	70	14
Severity Index	2.54	2.57

TABLE 9. PERCENT OF PDO, INJURY, AND FATAL ACCIDENTS BEFORE AND AFTER INSTALLATION OF GREEN-EXTENSION SYSTEM (THREE LOCATIONS)

TYPE OF ACCIDENT	PERCENT OF TOTAL ACCIDENTS	
	BEFORE PERIOD	AFTER PERIOD
PDO	64	71
Injury	33	29
Fatal	3	0
All	100	100

DATA COLLECTION AT NEW GREEN-EXTENSION SITES

The next objective of this study was to determine the effect of green-extension systems on conflicts, speeds, and delays at high-speed, signalized intersections. To accomplish this, data were taken before and after installation of GES at two locations. Intersections chosen had been scheduled for installation of GES. This allowed data collection for the before condition and shortly after installation and timing of the systems. It was desirable to select sites in which the only change between the before and after period was the addition of the GES.

The two intersections selected were US 23 at Hoods Creek Pike in Ashland and US 27 at US 150 in Stanford. The sites offered contrasting geometric and traffic conditions. One day of before and after data were taken in Ashland. Two days of data collection were completed for each of the before and after periods at Stanford because of low traffic volumes. Data collection began at 8:00 a.m. and ended at 6:00 p.m. each day. Data were collected and recorded in 15-minute intervals. One 15-minute break was usually taken each hour. A 30- to 45-minute lunch break was also taken during each test day. Details of the data collection procedures are given in APPENDIX B. Data forms used for collection of conflict, delay, and speed data are provided in APPENDIX C.

To document the accident problems at each of the test sites, several years of accident data were obtained from state and local police agencies. At the Ashland site (see Table 10), there were 27 rear-end accidents on the two major approaches between January 1, 1971, and May 1, 1976, and 18 of these were on the downhill (northbound) approach. There were 15 right-angle accidents on the southbound approach (five of them at night) largely due to southbound vehicles running the red light. These right-angle accidents accounted for nine injuries. (Right-angle accidents were assigned to the major approach in Table 10, so none are shown for Hoods Creek Pike.) The high number of rear-end and right-angle accidents indicated a dilemma-zone problem at this location.

At the Stanford site, 28 of the 32 accidents were right-angle or rear-end accidents (Table 11). The relatively high side-street volume on US 27, combined with a dilemma-zone problem, resulted in 20 right-angle accidents between January 1, 1973, and June 1, 1976. There were only five rear-end accidents on US 27, largely due to the low AADT which contributes to larger vehicle gaps and less chance for rear-end accidents. There were four sideswipe and other accidents during this time period. Because the accident reports prepared by the Stanford City Police were incomplete, a detailed classification of accidents by type and injury was not possible.

TRAFFIC CONFLICTS ANALYSIS

A traffic conflict is a traffic violation or an evasive action, such as braking or weaving, which is forced upon a driver to avoid an accident. Traffic conflicts are measures of accident potential and operational problems at a location. Conflicts may be used to quickly evaluate changes in road design, signing, signalization, and environment. Also, conflict studies can be completed with significant quantities of data in as little as two or three days of observation. An adequate sample of data for a before-and-after accident evaluation would take several years.

The first formal procedure for collection of traffic conflicts data was developed by the General Motors Research Laboratories in 1968 *(16)*. The basic categories of conflicts in this method are left-turn conflicts, weave conflicts, rear-end conflicts, and cross-traffic conflicts. There are 24 specific conflict types that were developed from these four basic conflicts for intersections *(16)*. This procedure is currently the basis for routine collection of intersection conflicts in the states of Ohio, Virginia, and Washington, although modifications have been made *(17)*. The conflicts used in this report were revisions of the General Motors method and were adapted to the dilemma-zone problem. The six types of conflicts should theoretically be reduced by the installation of an effective green-extension system. All conflicts were counted during or shortly after a yellow phase on the major street approaches. Although there are many other types of conflicts at an intersection, they were not considered to be related to GES installation. Most conflicts were discussed by members of the data collection team, especially if a conflict was not obvious. A brief discussion of the six conflicts follows.

Run Red Light – After talking with state and local police agencies, a "run-red-light" violation was defined as occurring when most of the vehicle is behind the stop bar the instant that the signal turns red.

Abrupt Stop – This conflict was not as clearcut as the run-red-light, and more judgement was required. An abrupt stop occurred when a vehicle made an unusually quick deceleration, particularly within 100 feet (30 m) of the stop bar. Usually, a noticeable "dipping" of the front end of the vehicle took place and there was an obvious last-second decision by the driver. Consistency in rating abrupt stops came only after observing several hundred vehicle stops. Questionable conflicts were always discussed among members of the team.

TABLE 10. ACCIDENT HISTORY FOR US 23 AT HOODS CREEK PIKE IN ASHLAND, KENTUCKY (1/1/71 to 5/1/76)

TYPE OF ACCIDENT	DAY	NIGHT	DRY	WET OR ICY	PDO	INJURY AND FATAL	TOTAL
Northbound Approach (US 23)							
Rear End	14	4	13	5	17	1(1)*	18
Angle	0	0	0	0	0	0	0
Sideswipe	2	0	2	0	2	0	2
Other	1	0	1	0	1	0	1
Southbound Approach (US 23)							
Rear End	7	2	9	0	8	1(2)	9
Angle	10	5	11	4	9	6(9)	15
Sideswipe	3	0	3	0	2	1(1)	3
Other	0	0	0	0	0	0	0
Eastbound Approach (Hoods Creek Pike)							
Rear End	0	0	0	0	0	0	0
Angle	0	0	0	0	0	0	0
Sideswipe	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0
Totals	37	11	39	9	39	9(13)	48

*( ) Number of injuries

TABLE 11. ACCIDENT HISTORY FOR US 27 AT US 150 IN STANFORD (1/1/73 TO 6/1/76)

TYPE OF ACCIDENT	NUMBER OF ACCIDENTS
Northbound Approach (US 27)	
Rear End	3
Angle	9
Sideswipe	1
Other	1
Southbound Approach (US 27)	
Rear End	2
Angle	10
Sideswipe	0
Other	0
Eastbound Approach (US 27)	
Rear End	1
Angle	1
Sideswipe	2
Other	0
Westbound Approach (US 150)	
Rear End	2
Angle	0
Sideswipe	0
Other	0
Total	32

Swerve-to-Avoid Collision – This conflict could actually be considered an erratic maneuver or near-miss-accident because of its closeness to an accident. These conflicts were rare and occurred only when a driver had to swerve out of his lane to avoid hitting the vehicle that had stopped for the light in front of him.

Vehicle Skidded -- This is a more severe case of an abrupt halt. It was identified by the rater actually hearing the vehicle skidding when the wheels "locked-up" to stop during the yellow phase.

Acceleration through Yellow -- This conflict was also quite difficult to discern in many instances. As finally interpreted by the rating team, an obvious case of "gunning" the vehicle shortly after the beginning of the yellow phase constituted an acceleration through yellow. It was required that the observer actually saw and heard a sudden acceleration before assigning this classification.

Brakes Applied before Passing Through -- This constituted an obvious split-second change in a driver's decision from stopping to acceleration through the signal on yellow. When a driver is caught in a dilemma zone, he may be uncertain whether to stop or pass through. An obvious case of braking the vehicle and then continuing through (not necessarily an obvious acceleration after braking) indicates that the driver was confused. Many drivers would apply brakes slightly as they approached an intersection on a downgrade to slightly decrease their speed (such instances were not considered as conflicts). Many conflicts in this category also could have been classified as acceleration through yellow, or as run red light. If a particular conflict could be classified under more than one category, it was classified under the most severe group.

Summaries of the numbers of conflicts at the two sites are shown in Tables 12 and 13. In Ashland (Table 12), there were 126 conflicts during the before period and 66 during the after period. The most frequent conflicts before GES was installed were run red light (89), abrupt stop (20), and brakes applied before passing through (10). During the after period the conflicts totaled 52, 20, and 10, respectively.

In Stanford, the number of conflicts decreased from 123 to 19 after installation of GES (Table 13). The majority of conflicts in the before period were acceleration through yellow (46), abrupt stop (39) and run red light (27). In the after period, these values were reduced to 9, 7, and 1, respectively. The conflicts at Stanford were for a total of 4 days of data collection, compared with only 2 days in Ashland.

To determine the statistical reliability that the GES reduces conflicts, a mean difference test (t-test) was used. The sampling periods were the 15-minute intervals for recording conflicts and volumes. The sample size, n, for Ashland was 29 in the before period (n_1) and 25 in the after period (n_2). The sample sizes for Stanford were 27 and 29. Where sample sizes are small (n less than 30), the normal distribution is not valid, and the t-test is applicable *(7)*. The probability of significance in the t-test is based on the variable t defined as

$$t = (\bar{x}_1 - \bar{x}_2)/S_p\sqrt{(1/n_1) + (1/n_2)}$$

where
$\bar{x}_1$ = sample mean of the before population,
$\bar{x}_2$ = sample mean of the after population,
n_1 = before sample size,
n_2 = after sample size,
S_p = pooled standard deviation,
= $\sqrt{((n_1 - 1)S_1^2 + (n_2 - 1)S_2^2)/f}$,
S_1 = standard deviation of n_1,
S_2 = standard deviation of n_2, and
f = number of degrees of freedom
= $n_1 + n_2 - 2$.

TABLE 12. DISTRIBUTION OF TRAFFIC CONFLICTS BEFORE AND AFTER INSTALLATION OF GREEN-EXTENSION SYSTEM IN ASHLAND (TWO DAYS OF DATA)

	BEFORE PERIOD	AFTER PERIOD	TOTAL	
			NUMBER	PERCENT
Run Red Light	89	52	141	73
Abrupt Stop	20	9	29	15
Vehicle Swerve to Avoid Collision	0	0	0	0
Vehicle Skidded	0	3	3	2
Acceleration Through Yellow	7	1	8	4
Brakes Applied Before Passing Through	10	1	11	6
Totals	126	66	192	100

TABLE 13. DISTRIBUTION OF TRAFFIC CONFLICTS BEFORE AND AFTER INSTALLATION OF GREEN-EXTENSION SYSTEM IN STANFORD (FOUR DAYS OF DATA)

	BEFORE PERIOD	AFTER PERIOD	TOTAL NUMBER	TOTAL PERCENT
Run Red Light	27	1	28	20
Abrupt Stop	39	7	46	32
Vehicle Swerve to Avoid Collision	2	0	2	1
Vehicle Skidded	3	0	3	2
Acceleration Through Yellow	46	9	55	39
Brakes Applied Before Passing Through	6	2	8	6
Totals	123	19	142	100

The mean conflicts per 15-minute period in Ashland were 4.34 and 2.64 for the before and after periods, respectively. In Stanford, the mean decreased from 4.22 to 0.66 after green extension. The t values were 2.17 for Ashland and 7.00 for Stanford. This corresponds to a probability of only .05 that the reduction in conflicts in Ashland was due to chance variation. The probability level for Stanford was only .001. The results are presented in Table 14.

Based on the mean number of conflicts per period, the number of conflicts per hour decreased after green extension from 17.4 to 10.5 in Ashland and from 8.4 to 1.3 in Stanford. This represents a reduction in conflicts of 39.7 percent in Ashland and 84.5 percent in Stanford. The average percent reduction in conflicts per hour at the two sites was 62.1.

Hourly variations of traffic conflicts during the test period (8:00 a.m. to 6:00 p.m.) are shown in Figures 5 and 6. In Ashland, conflicts were few before 11:00 a.m. and were roughly the same before and after GES installation (Figure 5). The number of conflicts per hour then increased between noon and 1:00 p.m. to about 27 and 21 for the two periods. Conflicts then declined during early afternoon before peaking between 4:00 and 5:00 p.m. to 32 (before period) and 12 (after period). In Stanford (Figure 6), conflicts before GES installation varied between 6 and 9 per hour before increasing steadily up to 20 per hour from 3:00 until 6:00 p.m. The conflicts after green extension in Stanford remained between 0 and 3 per hour throughout the day.

The hourly volumes throughout the day are shown in Figure 7 during the before and after periods at Ashland and Stanford. In Ashland, average hourly traffic volumes increased 15 percent from 1,398 in the before period to 1,610 in the after period (about 10 months later). In Stanford, a six-percent increase in hourly traffic volumes occurred during the after period from 425 to 452. Similarities can be seen in the shapes of the volume curves and "before" conflict curves for both locations. As volumes increase during the day, conflicts also tend to increase. This can be seen more clearly in Tables 15, 16, 17, and 18 which give traffic volumes and conflicts by time of day for the before period (Tables 15 and 17) and after periods (Tables 16 and 18).

TABLE 14. RESULTS OF T-TESTS FOR TRAFFIC CONFLICTS

	ASHLAND		STANFORD	
	BEFORE PERIOD	AFTER PERIOD	BEFORE PERIOD	AFTER PERIOD
n	29	25	27	29
mean	4.34	2.64	4.22	0.66
sd	3.59	1.68	2.58	0.86
t	2.17		7.00	
p	.05		.001	
f	52		54	

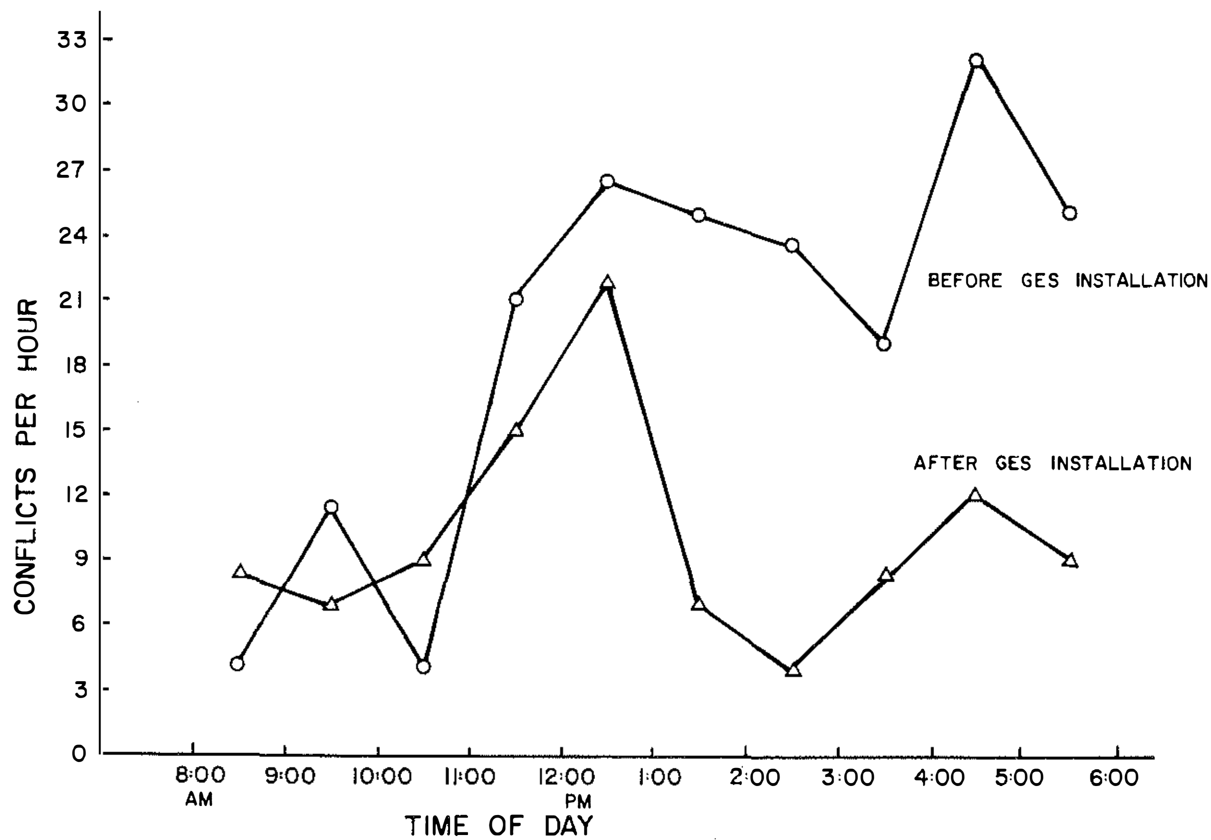
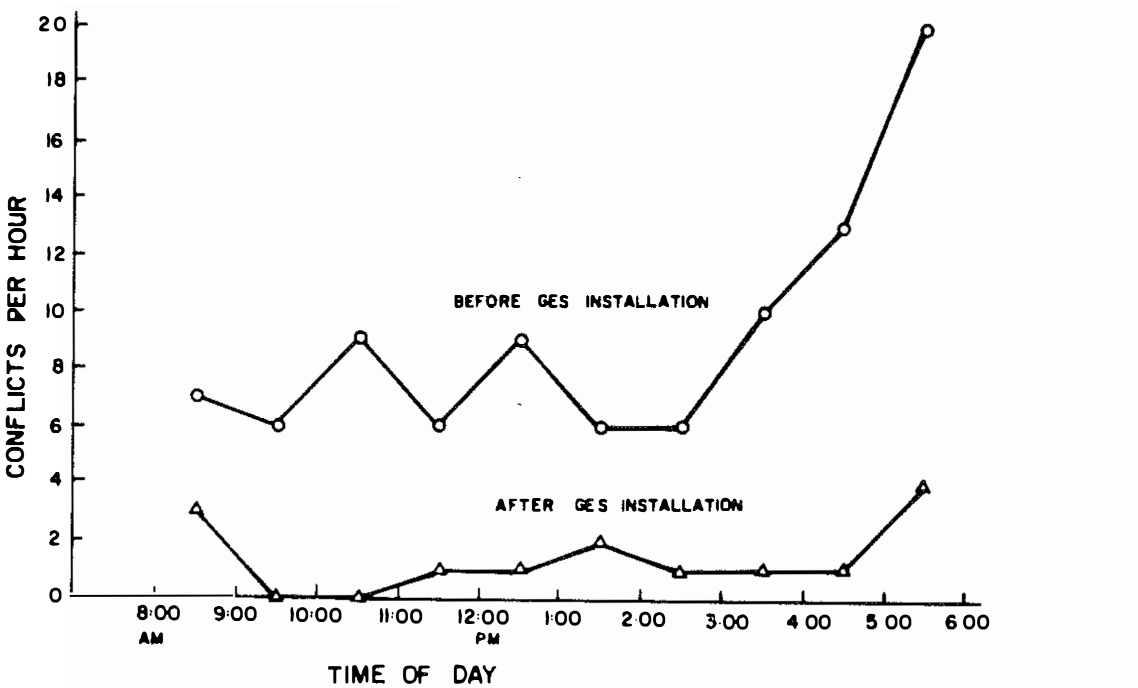


Figure 5. Conflicts at Ashland Site by Time of Day before and after GES Installation.

Figure 6. Conflicts at Stanford Site by Time of Day before and after GES Installation.



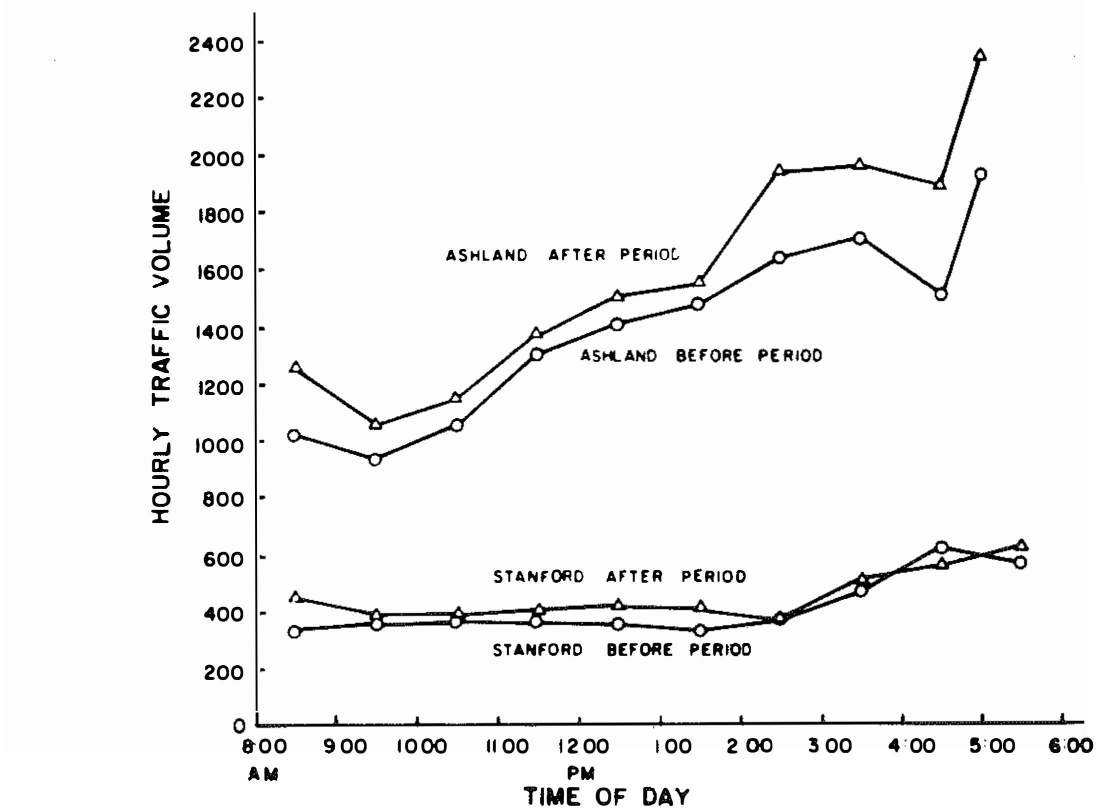


Figure 7. Hourly Traffic Volumes at the Test Sites.

TABLE 15. TRAFFIC VOLUME AND CONFLICT DATA FOR ASHLAND BEFORE GES INSTALLATION

TIME OF DAY	TRAFFIC VOLUMES (TWO-DIRECTIONAL) CARS	TRUCKS*	TOTAL	NUMBER OF CONFLICTS PER HOUR
8:00 to 9:00 a.m.	932	95	1,027	4
9:00 to 10:00	853	85	938	11
10:00 to 11:00	956	94	1,050	4
11:00 to 12:00	1,222	84	1,306	21
12:00 to 1:00 p.m.	1,320	83	1,403	26
1:00 to 2:00	1,390	90	1,480	25
2:00 to 3:00	1,548	96	1,644	23
3:00 to 4:00	1,607	97	1,704	19
4:00 to 5:00	1,431	75	1,506	32
5:00 to 6:00	1,867	56	1,923	25

*Vehicles with six tires or more are considered trucks

TABLE 16. TRAFFIC VOLUME AND CONFLICT DATA FOR ASHLAND AFTER GES INSTALLATION

TIME OF DAY	TRAFFIC VOLUMES (TWO-DIRECTIONAL) CARS	TRUCKS*	TOTAL	NUMBER OF CONFLICTS PER HOUR
8:00 to 9:00 a.m.	1,188	72	1,260	8
9:00 to 10:00	967	104	1,071	7
10:00 to 11:00	1,051	100	1,151	9
11:00 to 12:00	1,290	98	1,388	15
12:00 to 1:00 p.m.	1,416	90	1,506	22
1:00 to 2:00	1,471	97	1,568	7
2:00 to 3:00	1,856	92	1,948	4
3:00 to 4:00	1,853	113	1,966	8
4:00 to 5:00	1,819	77	1,896	12
5:00 to 6:00	2,290	52	2,342	9

*Vehicles with six tires or more are considered trucks

TABLE 17. TRAFFIC VOLUME AND CONFLICT DATA FOR STANFORD BEFORE GES INSTALLATION*

TIME OF DAY	TRAFFIC VOLUMES (TWO-DIRECTIONAL)			NUMBER OF CONFLICTS PER HOUR
	CARS	TRUCKS**	TOTAL	
8:00 to 9:00 a.m.	291	49	340	7
9:00 to 10:00	328	46	374	6
10:00 to 11:00	339	50	389	9
11:00 to 12:00	324	62	386	6
12:00 to 1:00 p.m.	319	51	370	9
1:00 to 2:00	303	42	345	6
2:00 to 3:00	329	55	384	6
3:00 to 4:00	410	60	470	10
4:00 to 5:00	554	58	612	13
5:00 to 6:00	530	53	583	20

*Based on two days of data collection
**Vehicles with six tires or more are considered trucks

TABLE 18. TRAFFIC VOLUME AND CONFLICT DATA FOR STANFORD AFTER GES INSTALLATION*

TIME OF DAY	TRAFFIC VOLUMES (TWO-DIRECTIONAL)			NUMBER OF CONFLICTS PER HOUR
	CARS	TRUCKS**	TOTAL	
8:00 to 9:00 a.m.	389	61	450	3
9:00 to 10:00	299	69	368	0
10:00 to 11:00	316	67	383	0
11:00 to 12:00	351	50	401	1
12:00 to 1:00 p.m.	346	63	409	1
1:00 to 2:00	344	62	406	2
2:00 to 3:00	328	64	392	1
3:00 to 4:00	440	65	505	1
4:00 to 5:00	517	65	582	1
5:00 to 6:00	567	54	621	4

*Based on two days of data collection
**Vehicles with six tires or more are considered trucks

Plots of traffic conflicts per hour versus hourly traffic volumes are shown in Figures 10 and 11. As expected, there was a positive, linear relationship between hourly conflicts and volumes in Ashland during the before period (Figure 8). The r^2 value was 0.54. All conflict and volume counts were adjusted to an hourly basis. There was no correlation for the after data at Ashland (r^2 = .02) where the GES significantly reduced conflicts. In Stanford (Figure 9), an r^2 of 0.73 indicated an excellent correlation between volume and conflicts during the before period. A somewhat lower correlation was found for the after period (r^2 = 0.39) where the conflicts were virtually insensitive to volume (practically a zero slope of the line).

Because of the direct relationship between conflicts and volumes before the GES's were installed, the increase in volume during the after period would indicate an expected increase in conflicts if no improvements were made. The large decrease in conflicts in spite of the volume increase further illustrates the effectiveness of green extension in reducing traffic conflicts.

An analysis was made of conflicts and conflict rates for cars and trucks to further evaluate green extension. To compute conflict rates, random counts were made of the number of turning vehicles on the two major approaches of both intersections. Right- and left-turning vehicles accounted for about 42 and 20 percent in Stanford and Ashland, respectively. The only vehicles which were considered for inclusion were the "through" vehicles on the major street at each intersection. Traffic volumes were adjusted to compute "through" volumes, which were divided then into the number of conflicts to obtain conflicts per 1000 through vehicles (Tables 19 and 20).

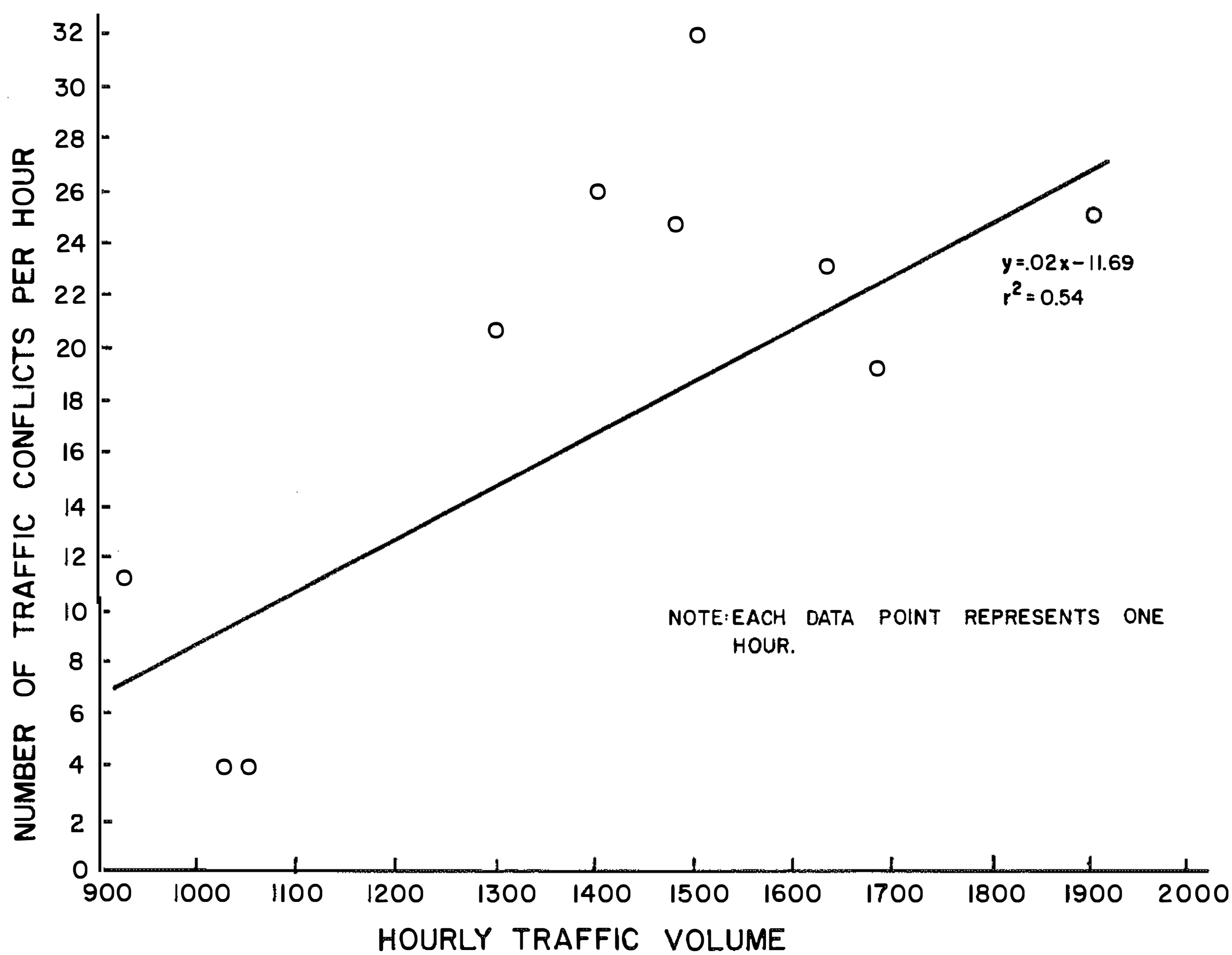


Figure 8. **Relationship between Traffic Conflicts and Hourly Volumes at Stanford Site before and after GES Installation.**

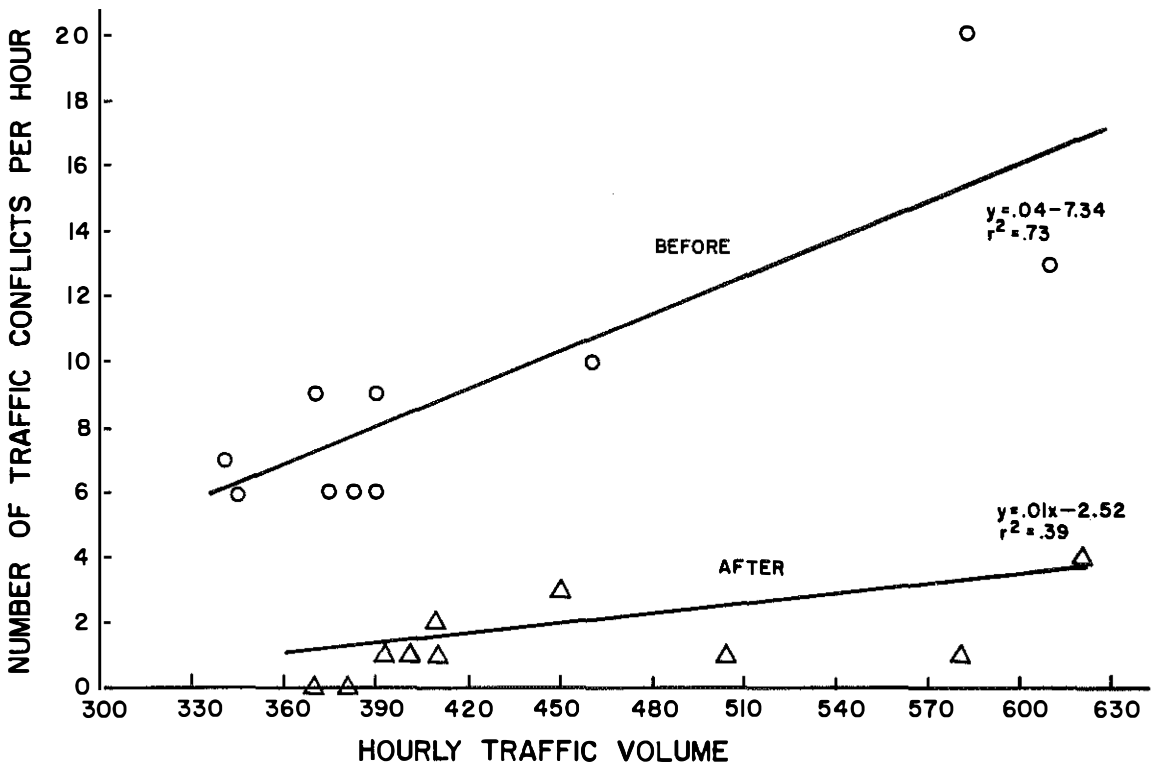


Figure 9. Relationship between Traffic Conflicts and Hourly Volumes at Ashland Site before and after GES Installation.

TABLE 19. TRAFFIC CONFLICT RATES FOR CARS AND TRUCKS IN ASHLAND

	BEFORE PERIOD				AFTER PERIOD			
	NUMBER		RATE (CONFLICTS PER 1000 VEHICLES)		NUMBER		RATE (CONFLICTS PER 1000 VEHICLES)	
	CARS	TRUCKS	CARS	TRUCKS	CARS	TRUCKS	CARS	TRUCKS
Run Red Light	80	9	10.7	18.2	44	8	5.8	17.6
Abrupt Stop	18	2	2.4	4.0	8	1	1.0	2.2
Vehicle Swerve to Avoid Collision	0	0	0	0	0	0	0	0
Vehicle Skidded	0	0	0	0	2	1	0.3	2.2
Acceleration through Yellow	7	0	0.9	0	1	0	0.1	0
Brakes Applied before Passing Through	10	0	1.3	0	1	0	0.1	0
Totals	115	11	15.3	22.2	56	10	7.3	22.0

TABLE 20. TRAFFIC CONFLICT RATES FOR CARS AND TRUCKS IN STANFORD

	BEFORE PERIOD				AFTER PERIOD			
	NUMBER		RATE (CONFLICTS PER 1000 VEHICLES)		NUMBER		RATE (CONFLICTS PER 1000 VEHICLES)	
	CARS	TRUCKS	CARS	TRUCKS	CARS	TRUCKS	CARS	TRUCKS
Run Red Light	20	7	6.3	16.3	1	0	0.3	0
Abrupt Stop	31	8	9.8	18.6	6	1	1.8	1.9
Vehicle Swerve to Avoid Collision	2	0	0.6	0	0	0	0	0
Vehicle Skidded	3	0	0.9	0	0	0	0	0
Acceleration through Yellow	37	9	11.7	20.9	9	0	2.7	0
Brakes Applied before Passing Through	5	1	1.6	2.3	1	1	0.3	1.9
Totals	98	25	30.9	58.1	17	2	5.1	3.8

In Ashland, the number of car conflicts decreased from 115 to 56; truck conflicts decreased slightly from 11 to 10. Conflict rates for cars decreased from 15.3 to 7.3 (conflicts/1000 vehicles) but remained nearly the same for trucks (about 22). Truck conflict rates exceeded those for cars during both periods. The most common conflicts for cars and trucks in Ashland were running red light, although the number and rate of these conflicts were reduced to half after green extension was provided (Table 19).

Truck conflict rates in Stanford were nearly double those of car rates in the before period, as shown in Table 20 (58 to 31). In the after period, the truck and car rates dropped to 5.1 and 3.8, respectively. Acceleration through yellow and abrupt stops were the most common conflicts for cars and trucks at Stanford in the before period, and they were drastically reduced by green extension. Note the conflict problem for all vehicles seems to have been solved in Stanford, while the dilemma-zone problem was not totally solved for trucks in Ashland.

An analysis of traffic conflicts by approach was also made at each intersection (Tables 21 and 22). In Stanford, there were large reductions in conflicts -- 95 percent on the northbound approach (46 to 2) and 78 percent on the southbound approach (77 to 17) (Table 23). In Ashland, there was a 60-percent reduction on the southbound approach but only a 40-percent reduction on the northbound approach (this approach had a 4-percent downgrade and limited sight distance). Both Stanford approaches are on about 3-percent downgrade, and the sight distance is excellent on the northbound approach and only slightly limited by a railroad overpass on the southbound approach. This analysis suggested that sight distance may be a major safety concern at high-speed intersections.

The analysis for each approach showed that the conflict rate (conflicts per 1,000 through vehicles) in Stanford was about twice the rate in Ashland before green extension was provided (Table 22). In Ashland, the rate dropped from 19.1 to 11.2 on the northbound approach and from 12.4 to 5.0 on the southbound approach. The rates in Stanford dropped from 33.8 to 1.2 and from 34.5 to 7.8 on the northbound and southbound approaches, respectively.

In any analysis employing traffic conflicts, an important consideration is rater consistency. Although great care was taken during field testing to rate conflicts consistently, an independent check was made in Ashland to determine reliability of the raters. Two raters independently counted conflicts on both approaches for 36 periods of 15 minutes each. The results are shown in Figure 10. The average number of conflicts per 15-minute period was 1.31 for Rater A and 1.36 for Rater B. The r^2 value was 0.75. Traffic conflict data were, therefore, judged to be highly reliable.

TABLE 21. NUMBER OF CONFLICTS BY APPROACH AT TEST SITES

	BEFORE PERIOD	AFTER PERIOD	PERCENT REDUCTION
Northbound Approach			
Ashland	76	46	40
Stanford	46	2	95
Southbound Approach			
Ashland	50	20	60
Stanford	77	17	78

TABLE 22. CONFLICT RATE BY APPROACH AT TEST SITES (NUMBER PER 1000 THROUGH VEHICLES)

	NORTHBOUND		SOUTHBOUND	
	BEFORE PERIOD	AFTER PERIOD	BEFORE PERIOD	AFTER PERIOD
Ashland	19.1	11.2	12.4	5.0
Stanford	33.8	1.2	34.5	7.8

TABLE 23. AVERAGE SPEEDS AT TEST SITES

PERIODS	SAMPLE SIZE	AVERAGE SPEED NORTHBOUND	AVERAGE SPEED SOUTHBOUND	AVERAGE SPEED TOTAL
Ashland				
Before	1,668	41.6	39.2	40.2
After	1,039	42.7	38.9	41.7
Stanford				
Before	596			40.8
After	794			43.6

TRAFFIC EFFICIENCY

An important consideration in the installation of green extension systems is their effect on traffic flow. The indicators used in this analysis were traffic speeds (free-flow), vehicle delay, number of non-stopping vehicles on the side street (no-stops), and stopped vehicles counted on the side street. All comparisons were made between the before and the after conditions.

Traffic Speeds

Random sampling was taken of free-flowing vehicles at each site before and after green extension was provided. Average speeds at the Ashland site were 40.2 mph (18.0 m/s) in the before period (sample of 1,668 vehicles). During the after period, the average was 41.7 mph (18.6 m/s) (sample of 1,039 vehicles), an increase of 1.5 mph (0.7 m/s). Northbound vehicles (downhill approach) were about 3 mph (1.3 m/s) faster than southbound vehicles (level approach). In Stanford, speeds also increased slightly from 40.8 mph (18.2 m/s) to 43.6 mph (19.5 m/s) (sample sizes of 598 and 794). Because the grades and geometrics of both approaches were virtually identical, speeds were combined. Speed summaries are given in Table 23.

Counts of Stopped Vehicles

A t-test was used to determine whether there was a significant change in the number of stopped vehicles on the side street after green extension was provided. The average number of stopped vehicles per 15-minute period is shown in Table 24. Averages were found on the side streets and on the major approaches at Stanford. In all cases, there was no significant change in the number of stopped vehicles after green extension was provided. Differences in mean vehicle counts ranged from 0.19 to 3.04 vehicles per 15-minutes. The green extension did cause a slight increase in the percentage of vehicles which stopped on the side street (from 71 to 77 percent).

Figure 10. Plot of Traffic Conflicts for Rater Reliability.

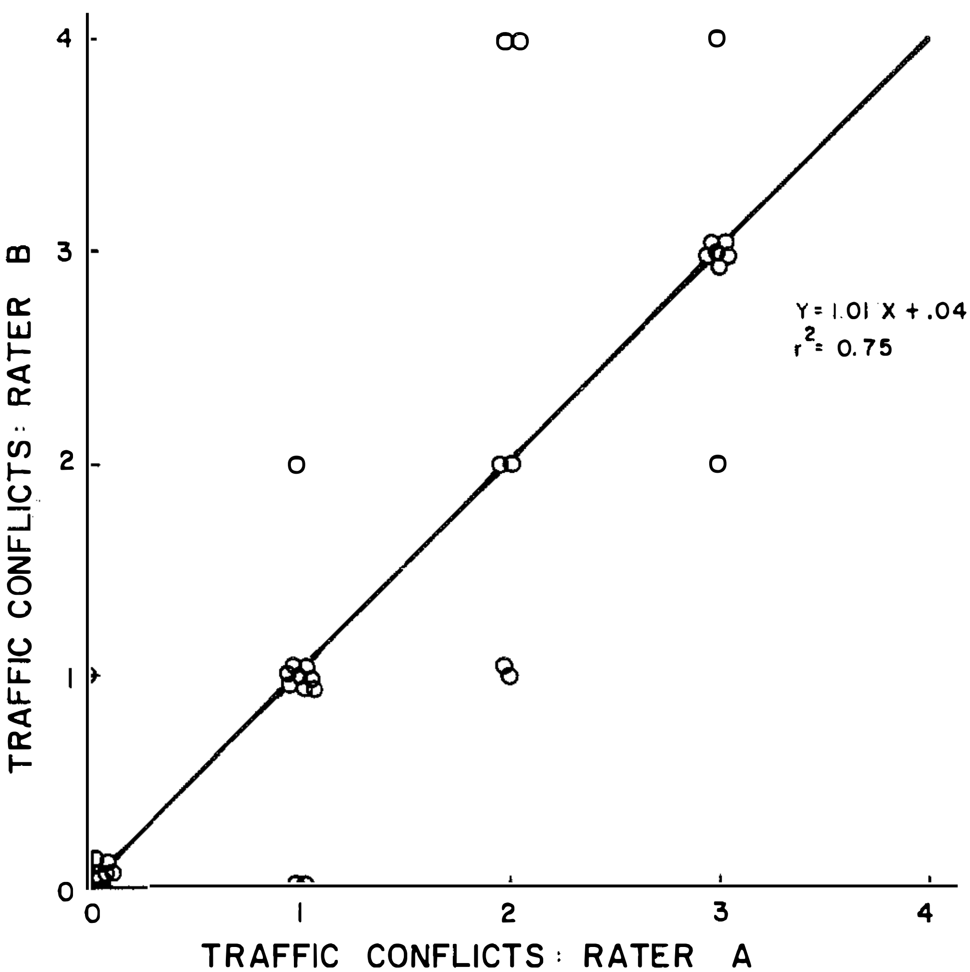


TABLE 24. RESULTS OF T-TESTS FOR STOPPED VEHICLES

	ASHLAND SIDE STREET		STANFORD SIDE STREET		STANFORD MAIN STREET	
	BEFORE PERIOD	AFTER PERIOD	BEFORE PERIOD	AFTER PERIOD	BEFORE PERIOD	AFTER PERIOD
n	29	25	27	29	25	29
mean	63.52	60.48	126.22	126.03	27.76	26.24
sd	35.72	42.62	32.54	42.63	11.56	18.56
t	0.29		.02		0.35	
p	ns*		ns		ns	
f	52		54		52	

Vehicle Delay

Hourly delays were computed for side-street vehicles at each site in terms of total delay (seconds). Plots were made of total hourly delay versus time of day in Figures 11 and 12. At both sites, the before and after periods showed reasonably similar values throughout the testing day. However, at both sites, the after period had lower delays around the noon rush hour and higher delays during the afternoon rush hour. No significant increase was found in side-street delay at either site.

No-Stop Vehicles

Another measure of traffic efficiency is the number of non-stopping vehicles on the side street. A reduction in the percentage of no-stop vehicles would suggest a reduction in the efficiency of traffic flow on the side street. The percentage of no-stops in Stanford during the before period was 28.3 compared to 23.0 during the after period. The average number of no-stops per hour for vehicles on the side street was 35.1 during the before period and 27.8 during the after period. There was a significant reduction in percent of no-stops within a .01 probability (Table 25). Right-turning vehicles were not considered in this analysis due to the allowable right-turn-on-red in Kentucky. Reliable no-stop counts were not available for the Ashland site because the high traffic volumes kept the observers occupied with collection of other data.

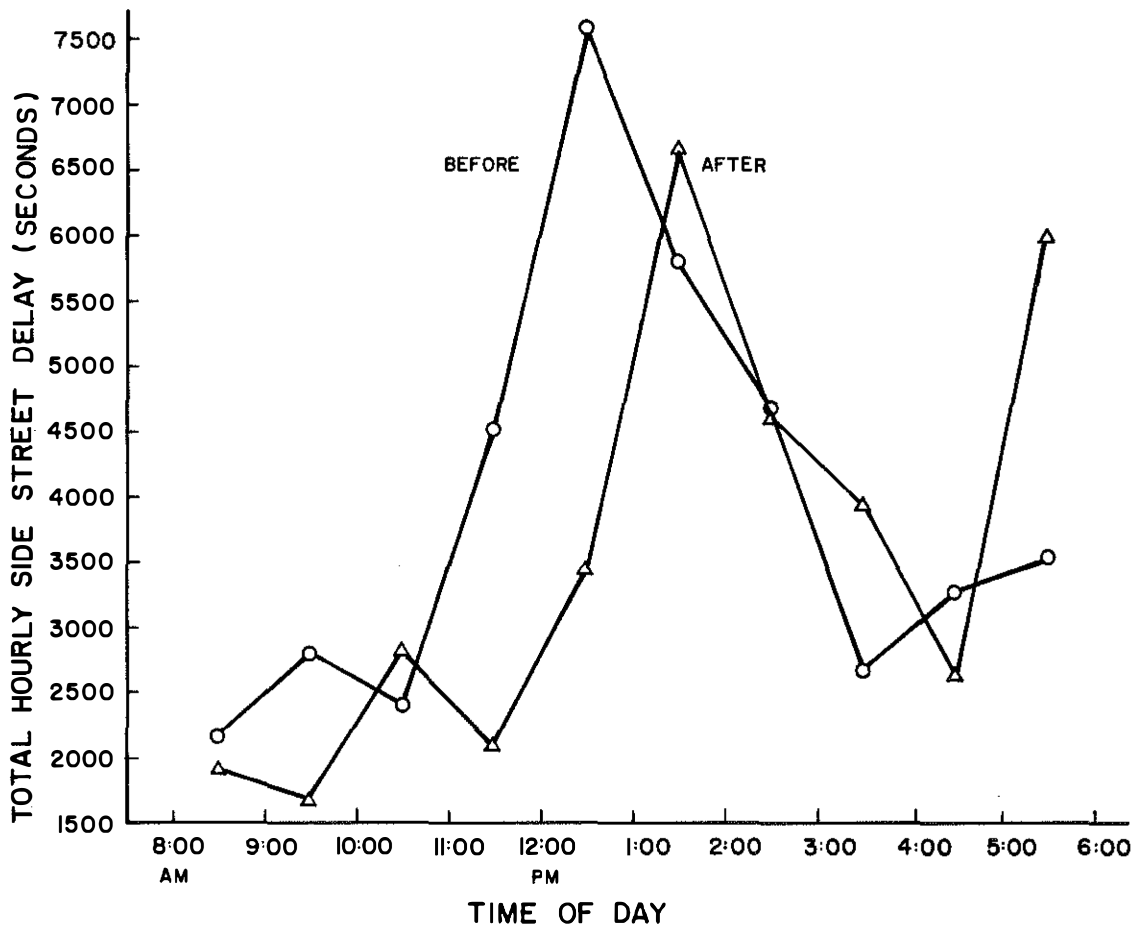


Figure 11. **Side-Street Delay versus Time of Day at Ashland Site before and after GES Installation.**

Figure 12. Side-Street Delay versus Time of Day at Stanford Site before and after GES Installation.

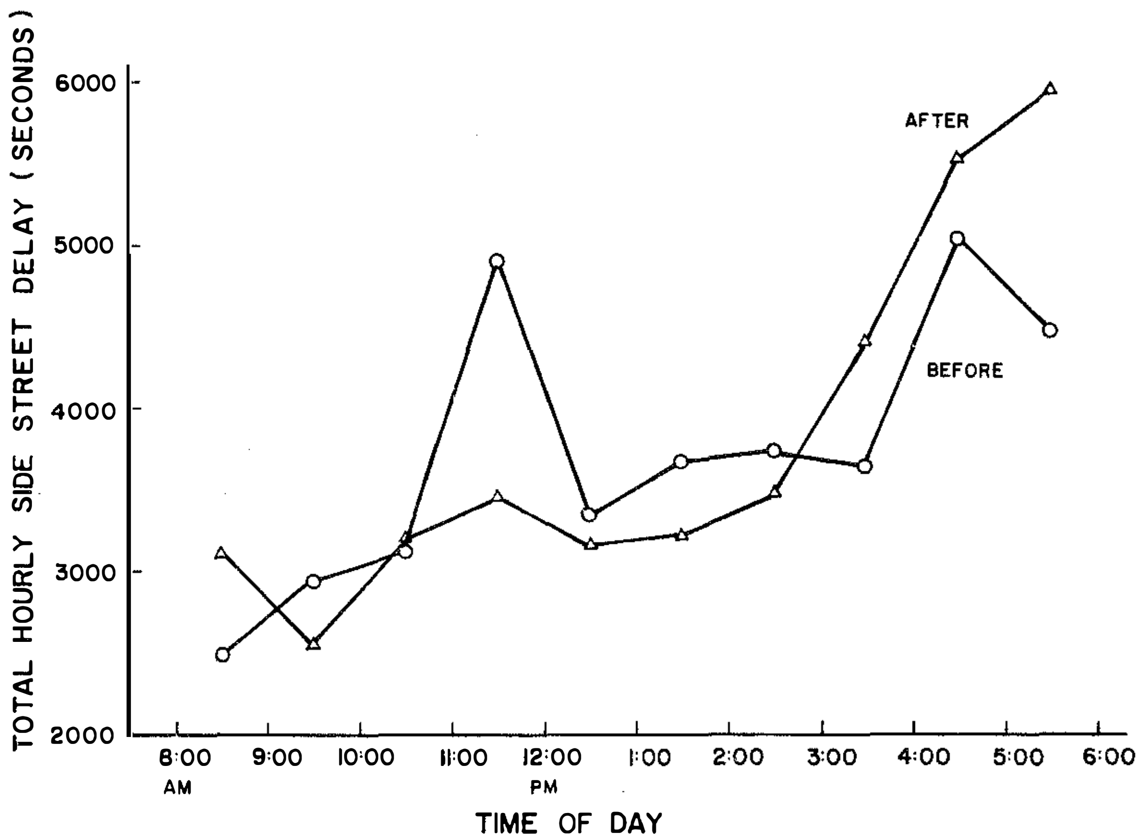


TABLE 25. PERCENTAGE OF NO-STOP VEHICLES ON SIDE STREET IN STANFORD

	BEFORE PERIOD		AFTER PERIOD
n (Time Periods)	10		10
Mean	28.3		23.0
Standard Deviation	3.40		2.74
t-value		2.77	
Probability		.01	

ECONOMIC ANALYSIS

The benefits of green extension were determined from an economic standpoint. The cost of an average accident to the highway user in Kentucky is $7,112. This cost was determined from National Safety Council accident cost data and the distribution of fatalities, injuries, and property damage accidents in Kentucky *(18)*. An annual interest rate of eight percent was selected. For installation of a green extension system to an existing signal system, initial cost is $2,750; and maintenance costs for a 10-year period are $500 per year.

Accident data showed that there was a 75-percent reduction in mainline, rear-end accidents after green extension was provided. This percentage was used with the $7,112 cost per accident to determine the annual accident savings for 1 to 12 rear-end accidents per year (Table 26). While there were also small reductions in several other accident types, only the reduction in rear-end accidents was statistically significant (within 95-percent probability) *(19)*. Present-worth benefits, benefit-to-cost ratio, and total net benefits were also computed for various accident levels (Table 26). Benefit-cost ratios ranged from 6 for 1 rear-end accident per year to 70 for 12 accidents per year. Total net benefits which might be expected from green extension (over the 10-year life) varied from about $29,000 to over $420,000, depending on accident history.

In the economic analysis, no delay costs were included since there was no significant change in vehicle delay at the two sites investigated. However, there is a possibility of increased delay at some high-volume intersections after green extension is provided. The current policy in Kentucky is not to provide green extension wherever unusual traffic delays would result. If increases in delay are later found to be a direct result of green extension, delay costs should be included in the economic analysis.

TABLE 26. COSTS AND BENEFITS OF GREEN EXTENSION

ANNUAL NUMBER OF MAINLINE REAR-END ACCIDENTS	ANNUAL ACCIDENT SAVINGS (DOLLARS)	PRESENT-WORTH COST (DOLLARS)	PRESENT-WORTH BENEFITS (DOLLARS)	BENEFIT/ COST RATIO	TOTAL NET BENEFIT (BENEFIT - COST)
1	$5,334	$6,105	$35,791	6	$29,686
2	10,668	6,105	71,582	12	65,477
3	16,002	6,105	107,373	18	101,268
4	21,336	6,105	143,165	23	137,060
5	26,670	6,105	178,956	29	172,851
6	32,004	6,105	214,747	35	208,642
7	37,338	6,105	250,538	41	244,433
8	42,672	6,105	286,329	47	280,224
9	48,006	6,105	322,120	52	316,015
10	53,340	6,105	357,911	59	351,806
11	58,674	6,105	393,703	64	387,598
12	64,008	6,105	429,494	70	423,389

SUMMARY AND CONCLUSIONS

1. A set of dilemma-zone curves was developed based on behavior of about 2,100 drivers. These data were compared to data from other sources.
2. A 54-percent reduction in total accidents was found at three intersections having the green extension. A 75-percent reduction in rear-end accidents and a 31-percent reduction in right-angle accidents were also found at these sites. The severity index was not affected.
3. Six types of yellow-phase conflicts were affected by the extension of green time and resulted in 39.7- and 84.5-percent reductions in these conflicts at sites in Ashland and Stanford, respectively. The average reduction in conflicts was 62.1 percent. These reductions were statistically significant.
4. A direct correlation was found between traffic conflicts and traffic volumes (r^2 values as high as 0.73).
5. Conflict rates (conflicts per 1,000 opportunities) at the Ashland site decreased from 15.3 to 7.3 for cars and 22.2 to 22.0 for trucks after the green extension was provided. In Stanford, the rate decreased from 30.9 to 5.1 for cars and 58.1 to 3.8 for trucks.
6. Restricted sight distance was found to be a major concern at high-speed intersections.
7. Average speed increased only about 1.5 mph (0.7 m/s) at the Ashland site and 3 mph (1.3 m/s) at the Stanford site after green extension was provided.
8. The percentage of non-stopping vehicles decreased from 28.3 to 23.0 after green extension was provided.
9. No significant change was found in the number of cars stopped or in total delay of vehicles on side streets after installation of green extension systems.
10. Installation of a green extension system at a signalized intersection will result in a present-worth net benefit of $29,000 to $420,000, depending on the accident history. Benefit-to-cost ratios ranged from 6 to 70, depending on the number of rear-end accidents per year on the mainline.

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APPENDIX A

GUIDELINES FOR THE INSTALLATION AND OPERATION OF GREEN-EXTENSION SYSTEMS
DIVISION OF TRAFFIC
November 1976

The Green Extension System (GES) is a signal system that has the ability to detect the presence of a vehicle before it travels into the dilemma zone and then insures that this vehicle will continue to have a green indication as it passes through the zone. The **dilemma zone** is defined as that zone in which the probability of stopping is greater than 10 percent and less than 90 percent.

WARRANTS

The Green Extension System should be considered for installation when the existing signal proves ineffective or as original equipment at locations judged by a qualified engineer to warrant their installation. As a minimum, the **Manual on Uniform Traffic Control** Devices (MUTCD) warrants must be met.

Existing non-Green Extension type signal installations should be considered for upgrading when accidents, such as rear-end type, continue to occur at a higher than normal rate or when on-site inspections reveal the existence of a stopping or dilemma zone problem. A Green Extension System would be considered as the original equipment for an intersection warranting signalization when the intersection has a sight distance deficiency, excessive grade on one or more approaches, or approach speeds in excess of 40 mph.

Once the decision has been made to consider the installation of a Green Extension System, in-depth studies should be conducted by the engineer.

These studies would generally include, but not be limited to, approach speed by vehicle classification, volume counts by classification, headways and gaps, and the effects of the physical layout such as grades, type of surface, drainage, and the presence of turning lanes.

VEHICLE DETECTION

The location of the advance detection loops should be determined on a case-by-case basis, with the primary considerations being dilemma zone location and approach speeds. The dilemma zone for our use is defined as that zone in which the probability of stopping is greater than 10 percent and less than 90 percent. It is within this dilemma zone that it becomes undesirable to display a red signal indication to an approaching vehicle.

The detection strategy to overcome this problem is to locate a vehicle detector in advance of the zone and then to extend the green time until the vehicle passes safely through the zone.

Normal procedure would be to install two stretch detectors, one in advance of the zone and one at the interior end of the zone. The stretch timer setting on the advance loop would be sufficient to allow the vehicle to pass through the zone and reach the interior loop. The time on the interior loop should, when added to the vehicle clearance interval, be sufficient to allow the vehicle to clear the intersection as is shown in Figure A1.

Standard procedure as co-ordinated with the Electrical Section dictates that each advance detector have its own stretch amplifier and that all stretch amplifiers for an approach be identified as such and attached together in an orderly manner, if practical. This facilitates tuning and timing.

A CASE STUDY

It is assumed that the decision has been made that a Green Extension System is warranted. Additional studies are now required. The first step would be to conduct a speed study by vehicle classification, the purpose being to determine the 50th- through the 95th-percentile speeds for both passenger cars and commercial size trucks.

The accident records should now be reviewed and a determination made as to the type of accidents occurring (truck-car, high speed-low speed, right angle-rear end). If no unusual accident patterns are apparent then the system should be designed for the 85th-percentile speed. The next step would be to determine the dilemma zone corresponding to this speed. In the event the accident experience indicates an abnormally high number of truck or high-speed accidents, the design speed for the advance loop should be the 90th- or 95th-percentile speed with the interior loop spacing corresponding to the lower percentile speed at which the problem ceases to exist. The time setting on the advance loop detector should be equal to the time it takes a vehicle to travel from the advance loop to the interior loop at the interior loop design speed. This same procedure could be used with three or more loops, the only limiting factor being the availability of suitable gaps so that other phase traffic can receive the green indication without the Green Extension phase being terminated by the maximum timer.

CONTROLLER SETTINGS

The fully-actuated controller configuration is now standard for the Green Extension Systems. The stretch detector is set according to loop spacings and design speeds. The green extension phase **will** be placed **in** the recall mode of operation with an **initial** green time on that phase sufficient to allow the traffic to begin moving over the interior loop and to prevent the signal from changing before the demand has been satisfied, generally 12 to 20 seconds. The **vehicle interval** should be set to zero since gap control or vehicle interval is now a function of the stretch detectors. Some controllers may require a time greater than zero to extend the green

-- in this case set 1/4 second on the controller and then reduce the stretch detectors by this amount. The **maximum time** feature on the controller for the Green Extension phase should be set to the maximum, generally 99 seconds. This maximum time will terminate the phase when a gap in traffic fails to occur. It is imperative that this maximum timer very rarely terminate the phase since it would defeat the purpose of the Green Extension System. If there exists any question concerning phase max out then a time lapse study should be conducted and a gap frequency determination made. The stretch timers can then be adjusted or if necessary the loop configuration altered. All previous experience has shown that, with random vehicle arrival, a gap in traffic should occur before the maximum timer terminates the phase for most non-urban, high-volume locations. The **vehicle clearance interval** should, when added to the interior loop stretch time, only be enough to allow the vehicle to pass through the intersection, since any additional time would be wasted. The **all-red feature** should be set to zero after the engineer is satisfied with the operation of the equipment. Any time set on the all-red only indicates a lack of confidence in the timing and reduces the overall operating efficiency of the intersection.

OTHER CONSIDERATIONS

The Green Extension System as we now use it can have any number of detectors on any phase; the only problem related to multi-phase operation is that each phase would need to operate in the recall mode of operation which could result in an operating efficiency deterioration. This is not desirable; therefore, should this condition result, the matter should be discussed with the Electrical Section and an alternate means of phase call made. All non-Green Extension approaches (phases) should continue to operate as they currently do; however, under no circumstance should the phase operate on recall. It would be very desirable to operate the phase in the non-lock mode with delay detectors installed to prevent the already departed right-turn-on-red vehicles from terminating the Green Extension Phase.

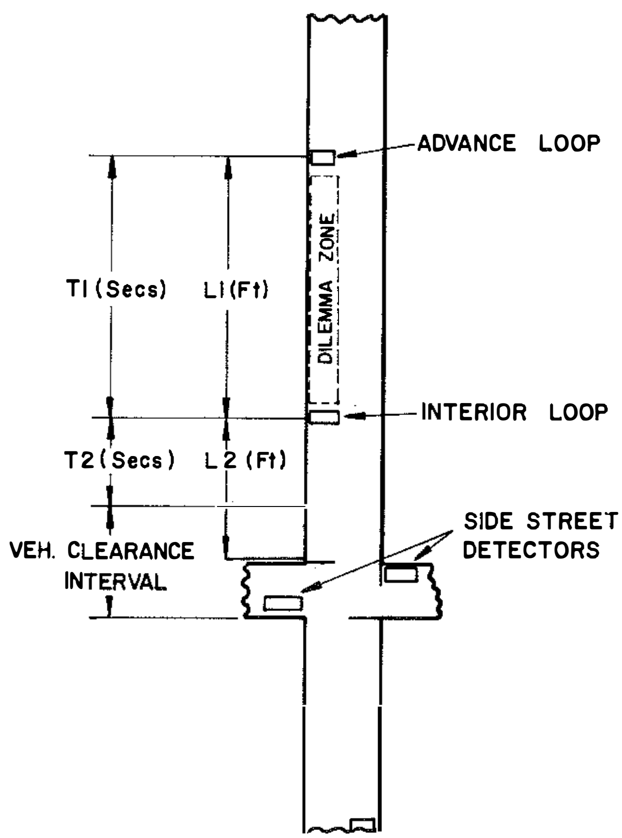


Figure A1. Dilemma Zone and Loop Location for a Typical Intersection.

APPENDIX B

DATA COLLECTION AT THE TEST SITES

Data Collection in Ashland

The site in Ashland was the intersection of US 23 (AADT of about 24,000) and Hoods Creek Pike (AADT of about 4,000) on the northwest side of town. The northbound approach of US 23 is a steep downgrade (four percent) with two lanes of traffic. The southbound approach has two lanes and a level approach. Hoods Creek Pike forms a T-intersection with US 23. A left-turn lane is provided for northbound vehicles onto Hoods Creek Pike. An unused left-turn lane is available for southbound vehicles turning into a closed side entrance of the Armco Steel Plant. (This entrance was not used during the before or after periods of data collection.) No separate left-turn phase exists there. A photograph and schematic diagram of this intersection are shown in Figures B1 and B2, respectively. The signal timing before and after GES installations are given in Table B1.

One state car was parked in the median facing northbound approximately 100 feet (30 m) south of the signal. Three data collectors were used for the before period (7-15-75), and four were there during the after period (5-18-76). Each day of data collection involved the following:

1. conflicts on northbound leg of US 23,
2. conflicts on southbound leg of US 23,
3. delay data on Hoods Creek Pike,
4. speed data on US 23, and
5. volumes of cars and trucks on US 23 approaches.

The six types of conflicts considered in this study were

1. run red light,
2. abrupt stop,
3. vehicle swerve to avoid collision,
4. vehicle skid,
5. acceleration through yellow, and
6. brakes applied before passing through yellow.

The duties of each data collector during the after period were as follows:

Man A was responsible for recording conflicts of northbound traffic and also watched for southbound conflicts whenever possible. He counted trucks (six tires or more) and cars on the northbound approach for each 15-minute period. A "T" was placed above each conflict involving a truck.

Man B was responsible for the southbound conflicts and volumes in the same manner as man A.

Man C kept track of the 15-minute periods for all data collectors and recorded side-street delays. He also counted car and truck volumes on the side street.

Man D recorded vehicle speeds in both directions on US 23.

Data Collection in Stanford

The site in Stanford was on the US 27 Bypass (AADT of 6,240) at US 150 (AADT of 3,056). This is a four-way intersection with downgrades of about three percent on both approaches of US 27. Separate right-turn lanes on US 150 in both directions (east and west) allow vehicles to turn right after yielding to traffic on US 27. Because of relatively low volumes on US 27 during most of the day, the right-turning vehicles experienced very little delay. Therefore, they were not included in the delay analysis.

The signal is traffic actuated with separate left-turn lanes on US 27, but there was no separate left-turn phase. There are four lanes on US 27 with separate left- and right-turn lanes. The side street (US 150) consists of one lane for through or left turns and separate right-turn lanes controlled by yield signs to minimize delay. Both approaches to the signal on US 27 are downhill with a grass median which is tapered to about 3 feet (see photograph in Figure B3). A schematic diagram of this intersection is given in Figure B4, and the signal timing is shown in Table B2.

Three people collected data from a state car which was parked about 100 feet (30 m) north of the intersection on US 27 facing south. The radar meter was mounted in the front or rear windshield and sighted on free-flowing vehicles travelling north or south down the hill toward the signal. The two days of data collection in Stanford before GES were July 29, 1975, and December 16, 1975. After data were collected on May 26 and 27, 1976. On all days, the following information was collected:

1. conflicts on north leg (southbound) of US 27,
2. conflicts on south leg (northbound) of US 27,
3. delay data on east leg (westbound) of US 150,
4. delay data on west leg (eastbound) of US 150,
5. count of the number of side-street vehicles turning left or going straight without having to stop,
6. volumes of cars and trucks during each 15-minute period,
7. volumes of side-street vehicles, and
8. speeds of vehicles approaching the signal during the green phase.

All conflicts involving a truck were marked with a "T". On the second day of data collection in Stanford (December 16, 1975), two additional types of information was collected. To determine the change in total intersection delay after installation of GES, mainline (US 27) delays were taken in addition to side-street delay. Also, to compute the approximate conflict rate (conflicts per "through" vehicles), the number of vehicles approaching on US 27 to turn right or left were counted during several 15-minute periods.

The six types of conflicts considered in this study were identical to the ones mentioned previously.

The duties of each of the three data collectors were as follows:

Man A was responsible for the southbound approach on US 27 and the eastbound approach of US 150. He sat in the front seat of the car on the passenger's seat to get the best view of this traffic flow. A clipboard with three counters were employed. Two counters were used for counting cars and trucks traveling southbound on US 27. Conflicts were observed during and shortly after the yellow phase of each cycle and noted if a truck was involved. During the side-street flow, a mark was made for every non-stopping vehicle traveling through or left on US 150. Also, a stopwatch was used for recording the number of mainline vehicles stopped on each approach at 15-second intervals. The third counter was used for counting the number of southbound vehicles turning left or right onto US 150.

Man B was responsible for the northbound approach on US 27 and the westbound approach on US 150. He sat in the driver's seat and mounted the radar scope alternately each hour in the front and rear window. Car and truck speeds were recorded at random during green intervals on US 27. Conflicts and volumes on the northbound approach were recorded. The number of non-stopping vehicles on the eastbound approach of US 150 were also marked on his conflict sheets.

Man C was responsible for delays and volumes on the side street. With a stopwatch, delayed vehicles were recorded on each approach of US 150 every 15 seconds. He also made volume counts of right-turning vehicles and left-and-straight vehicles on each approach of US 150 (four separate counts). He was responsible for keeping track of the start and end of each 15-minute period so all data on the counters could be transferred to data sheets on time.

TABLE B1. SIGNAL TIMING AT INTERSECTION OF US 23 AND HOODS CREEK PIKE IN ASHLAND, KENTUCKY

BEFORE GES INSTALLATION			
Phase A (US 23):	Maximum Green	=	35 seconds
	Amber	=	4 seconds
Phase B (Hoods Creek Pike):	Initial Interval	=	5 seconds
	Vehicle Interval	=	5 seconds
	Maximum Extension	=	20 seconds
	Amber	=	4 seconds
AFTER GES INSTALLATION (TIMED 9-1-76)			
Phase A (US 23):	Initial Interval	=	20 seconds
	Vehicle Extension	=	(1.5 seconds, 2.5 seconds, 1.6 seconds)*
	Maximum Extension	=	99 seconds
	Amber B	=	4 seconds
Phase B (Hoods Creek Pike):	Initial Interval	=	6 seconds
	Vehicle Extension	=	3 seconds
	Maximum Extension	=	35 seconds
	Amber	=	3 seconds

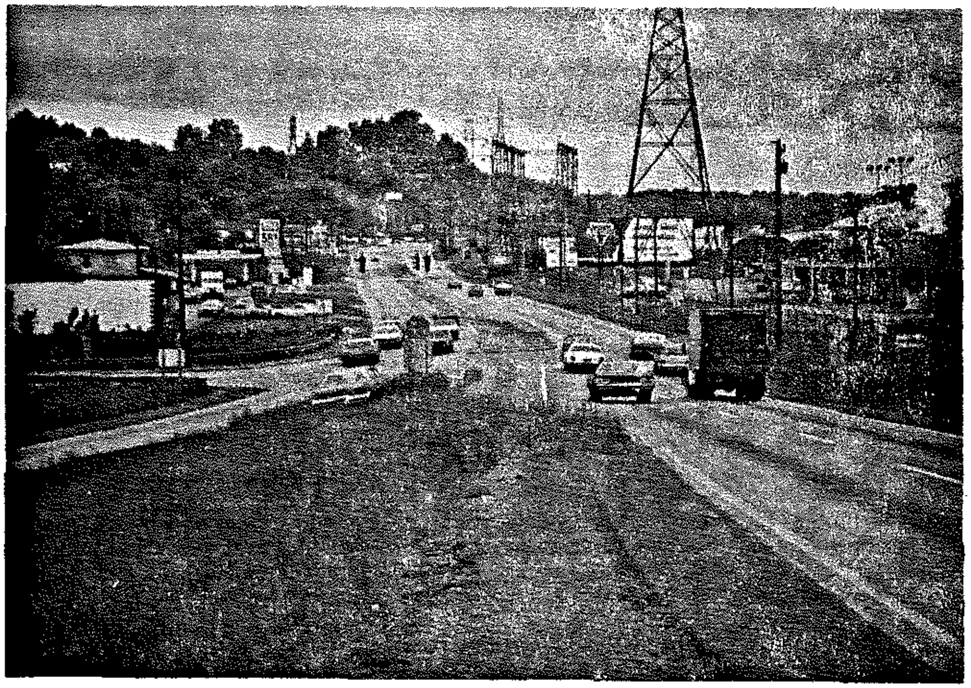
*Extension timing is for loops in order back from stop bar

TABLE B2. SIGNAL TIMING AT INTERSECTION OF US 27 AND US 150 IN STANFORD, KENTUCKY

BEFORE GES INSTALLATION			
Phase A (US 27):	Initial Interval	=	15 seconds
	Vehicle Interval	=	3 seconds
	Maximum Extension	=	40 seconds
	Amber	=	4 seconds
	All Red	=	3 seconds
Phase B (US 150):	Initial Interval	=	0 seconds
	Vehicle Interval	=	3 seconds
	Maximum Extension	=	25 seconds
	Amber	=	3 seconds
	All Red	=	3 seconds
AFTER GES INSTALLATION (TIMED 5-25-76)			
Phase A (US 27):	Initial Interval	=	15 seconds
	Vehicle Interval	=	(1.5 seconds, 4.5 seconds)*
	Maximum Extension	=	99 seconds
	Amber	=	4 seconds
	All Red	=	0 seconds
Phase B (US 150):	Initial Interval	=	0 seconds
	Vehicle Interval	=	2.5 seconds
	Maximum Extension	=	30 seconds
	Amber	=	3 seconds
	All Red	=	1 second

*Extension timing is for loops in order back from stop bar

Figure B1. Intersection of US 23 and Hoods Creek Pike in Ashland, Kentucky (Looking Northbound).



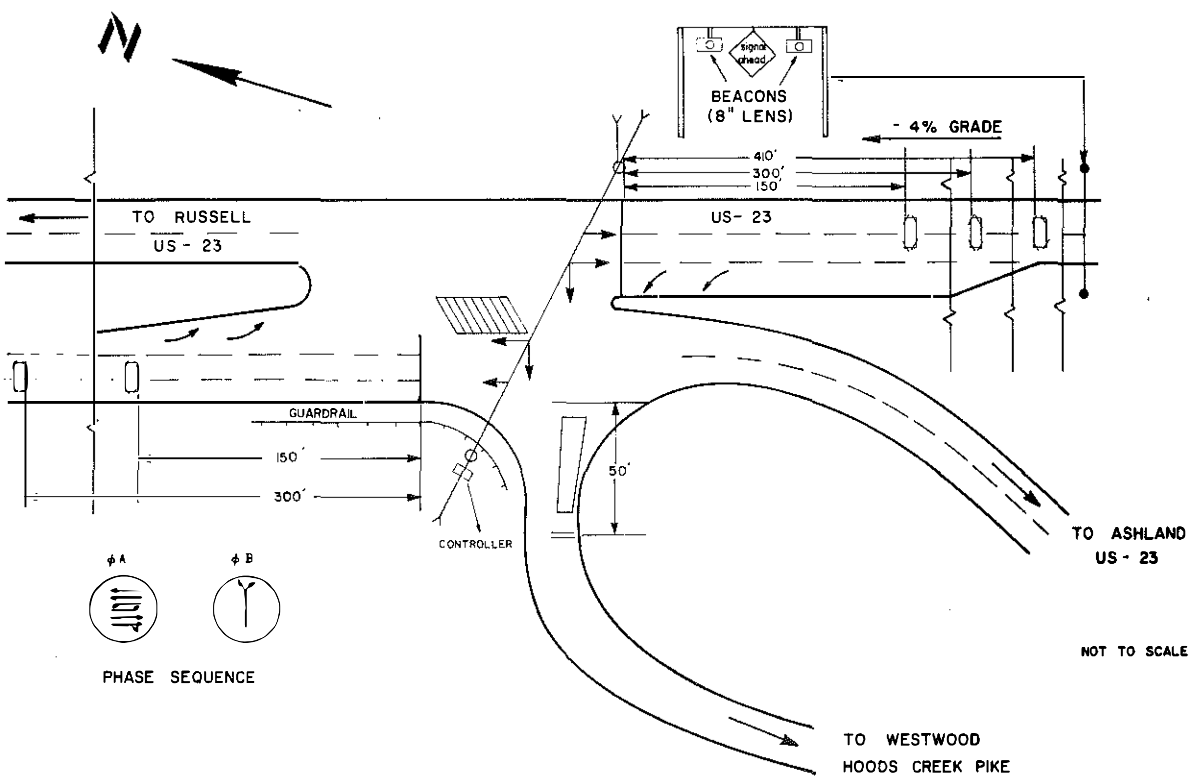
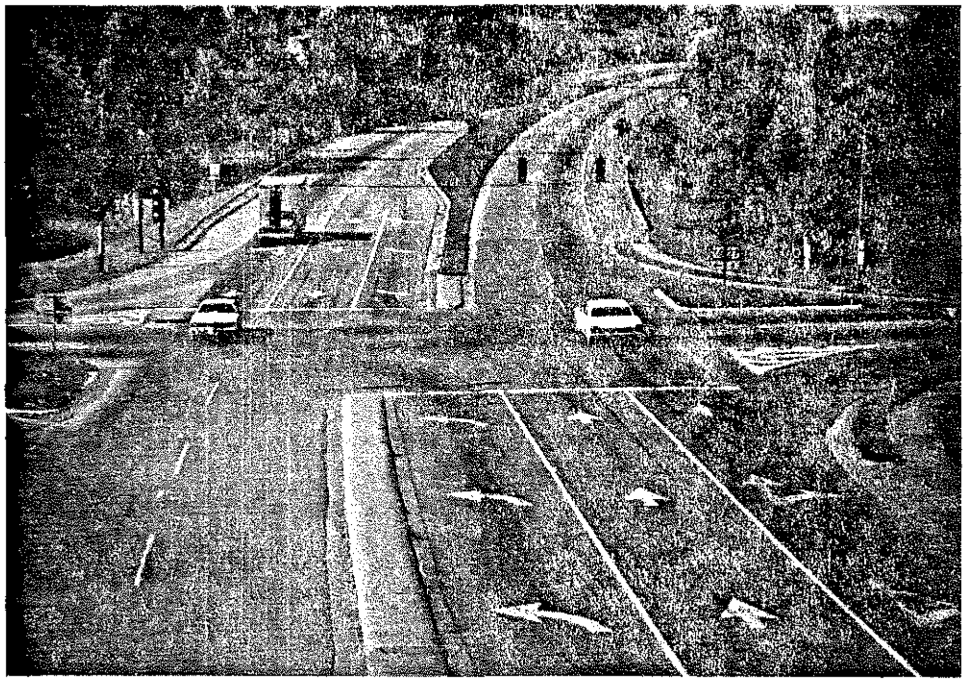


Figure B2. Diagram of Intersection of US 23 and Hoods Creek Pike in Ashland, Kentucky.

Figure B3. Intersection of US 27 and US 150 in Stanford, Kentucky (Looking Southbound).



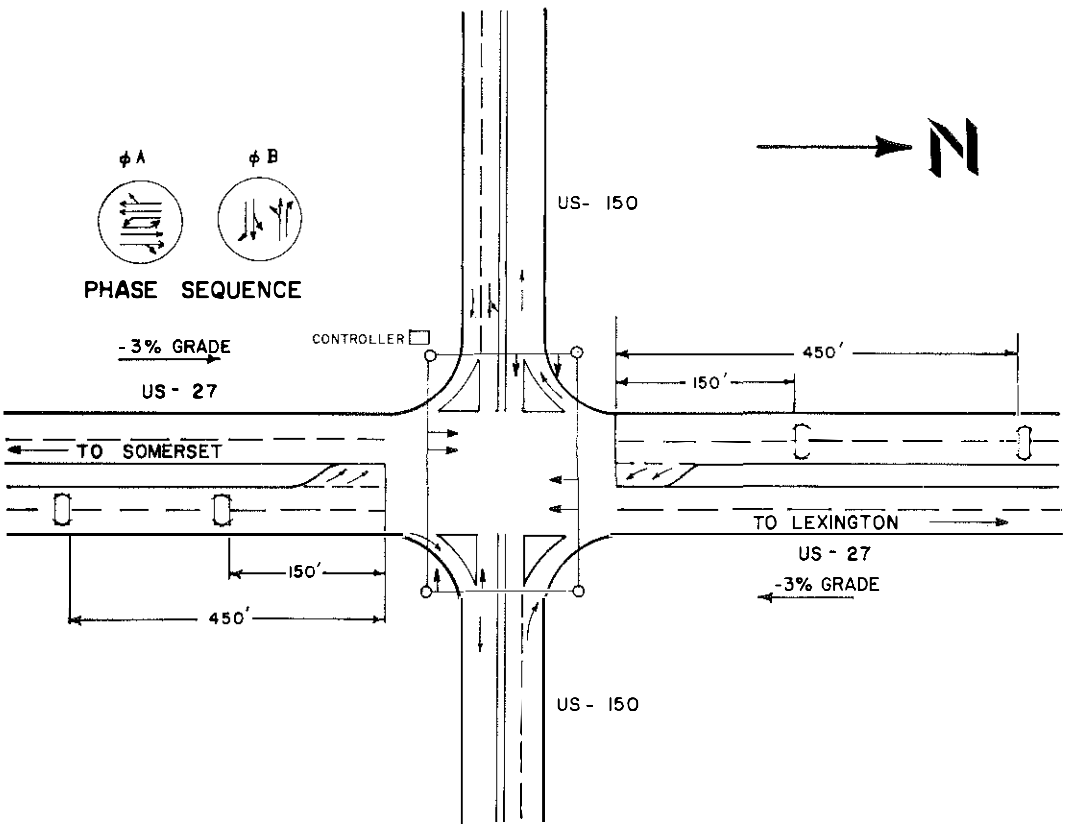


Figure B4. Diagram of Intersection of US 27 and US 150 in Stanford, Kentucky.

APPENDIX C

DATA FORMS FOR CONFLICTS, SPEEDS, AND DELAYS

CONFLICT STUDY FOR
GREEN LIGHT EXTENSION SYSTEMS

CITY ________________ COUNTY ________________ ROUTES ________________ and ____________ DIRECTION _________

SURVEYER _________________________ DATE ___________________

Time of Day	Total Traffic Volume (One Direction)	Number of Conflicts: Run Red Light	Abrupt Stop	Vehicle Swerve to Avoid Collision	Vehicle Skid	Acceleration Through Yellow	Brake Lights Applied Before Passing Through
___:00 to ____:15							
___:15 to ____:30							
___:30 to ____:45							
___:45 to ____:00							
___:00 to ____:15							
___:15 to ____:30							
___:30 to ____:45							
___:45 to ____:00							
___:00 to ____:15							
___:15 to ____:30							
___:30 to ____:45							
___:45 to ____:00							

MOTOR VEHICLE SPEED FIELD SHEET (RADAR)

COUNTY ROUTE NO. ZONE MPH DATE

TO DAY WEATHER N.S.E.W. BOUND

LOCATION

PAVEMENT CONDITIONS

REMARKS

SPEED	AUTOMOBILES	TOT.	CUMULATIVE TOTAL	CUMULATIVE PERCENT	SPEED	TRUCKS	BUSSES	CUMULATIVE TOTAL	CUMULATIVE PERCENT
100					100				
95					95				
90					90				
85					85				
80					80				
78					78				
76					76				
74					74				
72					72				
70					70				
68					68				
66					66				
64					64				
62					62				
60					60				
58					58				
56					56				
54					54				
52					52				
50					50				
48					48				
46					46				
44					44				
42					42				
40					40				
38					38				
36					36				
34					34				
32					32				
30					30				
28					28				
26					26				
24					24				
22					22				
20					20				
18					18				
16					16				
14					14				
12					12				
10					10				

DATA FORM FOR STOPPED VEHICLE COUNTS

:00														
:15														
:30														
:45														
1:00														
1:15														
1:30														
1:45														
2:00														
2:15														
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2:45														
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